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ART. I.—*The Age of the Earth;* by CLARENCE KING. With Plates I and II.

AMONG the various attempts to estimate geological time none has offered a more attractive field for further development than Lord Kelvin's mode of limiting the earth's age from considerations of its probable rate of refrigeration, published in 1862.* At that time the consequences of his physical reasoning could not be fully applied to the conditions within the earth, so as to test the probability of his hypothetical case, for want of positive knowledge of certain properties of rocks, particularly the volume changes of melted rock in approaching and experiencing congelation, and the qualitative and quantitative effects of pressure upon the fusion and freezing points. Data then lacking are for the first time available, and with them it is proposed to apply a new criterion to the gradient of Lord Kelvin and to compare with it other cases of more probable earth-temperature distribution, which should have the effect of advancing his method of determining the earth's age to a further order of importance.

Accepting the hitherto unshaken results of Kelvin and G. H. Darwin, as to the tidal effective rigidity of the earth, and the further argument for rigidity advanced by Prof. S. Newcomb† from the data of the lately ascertained periodic variation of terrestrial latitude, as together warranting a firm belief in the rigid earth, it follows that solidity may be used as a criterion

* Treatise on Natural Philosophy, Thomson and Tait, Part 2, Appendix D.
† Monthly Notices of the Royal Astronomical Society, vol. lii, No. 5, 1892.

to test the probable truth of many cases of earth-temperature distribution; at least so far as to justify the rejection of such as involve considerable liquidity of the upper couches. In an earth of which the superficial quarter of radius is composed of materials that contract from the fluid condition toward and in the act of congelation, any temperature gradient in which the downward heat augmentation exceeds the rate by which advancing pressure raises the fusion point, would obviously reach a fused couche, and all such distributions may be rejected as violating the requirements of rigidity.

A recent investigation of the rock diabase in its relations to heat and pressure offers the formerly lacking means of testing the admissibility of many cases of earth-temperature distribution from the point of view of solidity. Ten years ago in a laboratory established by me in connection with the United States Geological Survey, Dr. Carl Barus began a series of experimental researches tending toward the solution of some of the unknown but important points of geological physics. It has been my privilege to indicate the direction of much of the inquiry. The understanding between us maintained his entire independence in the mode and prosecution of the investigations and secured for him the fullest responsibility and credit for the purely physical results, many of which have at intervals appeared in this and other journals. For myself was reserved the privilege of making geological applications of the laboratory results. One of the most important of these is Dr. Barus's lately completed determination of the latent heat of fusion, specific heats melted and solid, and volume expansion between the solid and melted state, of the rock diabase.* To him I am also very generally indebted for aid in considering the present problem.

Diabase was chosen by me as fairly illustrative of the probable density and composition of the surface ·03 or ·04 of the earth's radius. For Laplace's law of distribution, density at the surface is taken at 2·75 and down one-tenth of radius at 3·88, yielding a mean density of the whole tenth of 3·33 and for the upper five-hundredths of about 3. For the whole tenth a rock like the extremely heavy basalt of Barenstein† (sp. gr. 3·35) would approach closely a fair mean expression of density. Typical hornblende-andesite comes closest to the average density at the surface, but diabase (sp. gr. 2·8 to 3·), nearly enough fills the conditions of the shell which this study seeks to investigate. The particular diabase under examination came from Jersey City, and was taken from the immediate vicinity of the Pennsylvania R. R cut.

* This Journal, Dec., 1891, and Jan., 1892.
† J. Roth, Gesteins-Analysen, 1861, p. 46.

The following analysis is by G. W. Hawes:*

Silica	53·13
Alumina	13·74
Ferrous oxide	9·10
Ferric oxide	1·08
Manganous oxide	0·43
Lime	9·47
Magnesia	8·58
Soda	2·30
Potash	1·03
Ignition	0·90
	99·76

Astronomical and geodetic requirements make necessary that density should proceed downward in shells of successively greater value, but the surface density is 2·75 and the mean density of the whole earth is not twice that of diabase, whence it appears that no probable chemical distribution of material could result in a surface couche of ·05 of radius having a greater specific gravity than 3· to 3·3.

Waltershausen† in his interesting scheme of chemical distribution attempts to account for the augmentation of density chiefly by the increase of the heavy bases, but leaves the whole surface tenth of radius in silicates. Eruptions of alkaline earths or metals are unknown, in fact, with the exception of carbonates of superficial origin the whole visible body of the crust is of silicates, and the earliest rocks are seen to be made of the debris of still older ones. All that can be said is that there is absolutely no known reason why the surface tenth of radius may not be of silicates, nor why specific material of widely different thermal properties from diabase should be postulated.

The two principal conditions within the interior of the earth upon which physical state and all purely physical reactions of the specific materials depend, are the distributions from center to surface of pressure and heat. Secular or sudden variations of either or both have the power, if carried sufficiently far, to disturb chemical and physical equilibrium and produce changes of volume, rigidity, viscosity, and conductivity, as well as changes of state from liquidity to solidity, and the reverse. Before proceeding to consider in detail some of the results of heat and pressure as existing in the surface ·05 of radius, it is desirable to glance at the relations of these two great antagonistic

* This Journal, III, vol. ix.

† "Rocks of Sicily and Iceland."

energies in the whole radius. Plate I gives earth-pressures from Laplace's law expressed in a gradient of which the ordinates are 100,000 atm. (larger divisions 1,000,000 atm.) and the abscissæ tenths of radius. Upon the same diagram are delineated two hypothetical cases of earth-temperature, the abscissæ remaining as for the pressure line, tenths of radius, and the ordinates corresponding in interval to the 100,000 atm. lines, are taken as each 1,000° C. The left vertical boundary of the plate represents the center of the earth and the right one the surface. The upper heat gradient corresponding to a temperature of 3,900° C. at the earth's center is the 100×10^6 curve of Kelvin. The lower is computed for a central temperature of 1,741° C., about the melting point of platinum, and a secular cooling in 20×10^6 years. Data for the construction of these gradients are given in the tables a few paragraphs later. The feature here called attention to is the exceedingly slight change of temperature from very near the surface downward to the center. In the Kelvin gradient even after the lapse of 100×10^6 years the original maximum temperature is reached within ·05 of radius and remains thence unchanged to the center. Pressure, on the other hand, augments with one downward sweep through the entire radius. On Plate I its line is seen cutting both temperature gradients near the surface, passing the 1,741° C line at a pressure of 175,000 atm., and the Kelvin line at 390,000 atm.; thence steadily augmenting until at the center it reaches the impressive figure of 3,018,000 atmospheres.

Since we are to look to heat and pressure for the keys to the physical condition of the matter of the earth, it is important to realize from the relation of these gradients, first, that the great effect of heat in opposing and overcoming the results of pressure must be limited to superficial earth-depths not exceeding 200 miles for an earth of the Kelvin assumptions; secondly, that below this depth and onward to the center there is a complete reversal of relations and a great and continual increase of pressure available to oppose and destroy the volumetric and other molecular effects of a temperature which has ceased to increase. The empire of heat over pressure is thus seen to be purely superficial, while that of pressure over heat begins not far below the surface and extends more and more powerfully to the center. This is obviously true only for such moderate assumptions of heat and time as are given in the gradients on Plate I, but it will be shown later that these figures are, upon the criterion of solidity, far more probable than very hot or very old earths.

Out of the infinite number of possible earth-temperature gradients, to discriminate the probably true case, is of critical

importance in any attempt to determine the earth's thermal age or to delimit the period of active geological dynamics.

Pressure and Temperature Tables.

The following tables offer figures for the construction of the pressure and some of the temperature gradients on both Plates I and II. Data for the distribution of earth-pressure may be obtained either from the formula of Laplace or that of G. H. Darwin for radial earth density, combined with the known decrease of terrestrial gravitation from center to surface.

In table 1, Laplace's law is used as giving the most conservative values of density at great depths. For the superficial ·2 of radius, however, the two density laws are near together, and as the thermal phenomena which determine the earth's age are probably wholly in the surface tenth, either law might be applicable to the present purpose. As, however, Darwin's law requires a surface density of 3·7, while Laplace only 2·75, the latter accords better with the average specific gravity of superficial rocks and is, therefore, here preferred.

Tables 2, 3 and 4 give data for three temperature gradients derived by mechanical quadrature from the well known Fourier equation in the manner given by Lord Kelvin, and are considered as sufficient in number and variety to indicate the character of the data; figures for the other gradients shown on Plate II are therefore omitted.

Table 2 presents data for the Kelvin gradient, 3,900° C. initial excess, surface rate ·03600 in degrees Centigrade per meter of depth, and secular cooling 100×10^6 years. Earth temperatures in ° C. are given for depths that are expressed both in miles and fractions of radius and extend to 250 miles or about ·06 of radius. Surface rate appears both in ° Fahr. and feet, and ° C. and meters. Tables 3 and 4 exhibit similar data for earths of lower initial excess and shorter periods of secular cooling. Table 3 is computed for an earth of 1,740° C., 20×10^6 secular cooling, and table 4 for 1,230° C., 10×10^6 cooling.

TABLE NO. 1.

Estimated Earth Pressures (Laplace's densities) n being radial distances from the center of the earth and p being the pressure corresponding to n expressed in atmospheres.

n. Earth Rad.	p. Atm.	n. Earth Rad.	p. Atm.	n. Earth Rad.	p. Atm.
1·000	0	·94	116000	·5	1680000
·995	8600	·92	162000	·4	2100000
·990	17400	·90	199000	·3	2470000
·985	26400	·80	497000	·2	2770000
·980	35600	·70	852000	·1	2950000
·960	74500	·60	1260000	0	3020000

TABLE No. 2.

Estimated Earth Temperatures. Initial excess of 3900° C. 100 millions of years secular cooling with surface rate of 1° F. for 50·6 feet of depth. Thermal conduction 400 ft²/year (Lord Kelvin's case).

Miles deep.	Rate in ° F and ft.	Rate in ° C and meters.	Temperature in ° C.	Depth in earth radius.
0	·01977	·03600	0	·00000
12	·01924	·03510	726	·00312
25	·01773	·03230	1412	·00625
50	·01279	·02330	2543	·01250
75	·00742	·01350	3275	·01875
100	·00346	·00630	3658	·02500
125	·00129	·00236	3825	·03125
150	·00039	·00071	3881	·03750
175	·00009	·00017	3897	·04375
200	·00002	·00003	3901	·05000
225	·00000	·00001	3902	·05625
250	·00000	·00000	3902	·06250

TABLE No. 3.

Estimated Earth Temperatures. Initial excess 1741° C. (about melting point of platinum) 20 millions of years secular cooling with surface rate of 1° F. to 50·6 feet of depth. Thermal conduction 400 ft²/year.

Miles deep.	Rate ° F and feet.	Tempera-ture ° C.	Depth in earth radius.
0	·01977	0	·00000
6	-----	359	·00156
12	·01726	693	·00312
25	·01147	1218	·00625
37	·00581	1534	·00937
50	·00224	1675	·01250
62	·00066	1725	·01562
75	·00015	1738	·01875
87	·00002	1741	·02187
100	·00000	1741	·02500

TABLE No. 4.

Estimated Earth Temperatures. Initial excess 1230° C., 10 millions of years secular cooling with surface rate of 1° F. to 50·6 feet of depth. Thermal conduction 400 ft²/year.

Miles deep.	Rate ° F. and feet.	Temperature ° C.	Depth in earth radius.
0	·01977	0	·00000
12	·01506	662	·00312
25	·00665	1063	·00625
37	·00171	1198	·00937
50	·00025	1227	·01250
62	·00002	1230	·01562
75	0	1231	·01875
87	0	1231	·02187
100	0	1231	·02500

TABLE No. 5.

Estimated Melting Point and Depth for the rock Diabase expressed in radial earth distance, pressure and melting temperature.

n. Earth Rad.	p. Atm.	θ_m. ° C.	n. Earth Rad.	p. Atm.	θ_m. ° C.
1·000	0	1170	·920	162000	5210
·995	8600	1380	·900	199000	6100
·990	17400	1600	·8	497000	14000
·985	26400	1830	·6	1260000	33000
·980	35600	2060	·4	2100000	54000
·960	74500	3030	·2	2770000	71000
·940	116400	4080	·0	3020000	76000

Table 5 contains a prolongation of Barus's line of melting point and depth for the rock diabase, expressed in radial earth distance n, pressure p (Laplace's densities), and melting temperatures, θ_m.

The Chart.

The chart constituting Plate II is constructed to present the passage of certain hypothetical temperature gradients through the uppermost ·08 of the earth's radius, and the position in the same field of Barus's line marking the melting point in depth of diabase, thus defining the relations of the various distributions of earth-temperature to liquidity. The value of the ordinates is each one thousand degrees Centigrade; the abscissæ, which are platted as equal in length to the ordinates, represent hundredths of radius counting downwards from the surface which is indicated by the right vertical boundary of the chart.

Kelvin's application of the Fourier equation involves an assumed initial excess of temperature, an assigned value of rock conductivity, a given period of secular cooling and the surface rate of augmentation of earth-temperature. As thus applied to the case of the cooling earth, it is obvious that while the body was of uniform initial heat there would be no augmentation of temperature from the surface downward, or otherwise expressed, the surface rate would be ∞; but the moment refrigeration began a finite rate of downward increment would be established. Since the earth's surface is represented on the chart by the right vertical boundary, that line would be the thermal distribution for the rate ∞. A complete process of refrigeration would cause the rate to decline until the earth reaches the temperature of space and the line of initial tangency coincides with radius, and the rate 0. The angular relation of the initial tangent of the present as compared with that of the rate ∞ is determined from observed surface augmentation.

The value of the integral and the surface rate for any gradient does not change if conductivity and age vary reciprocally, and the surface rate does not change if the initial excess of temperature varies at the same rate as the square root of the product of conductivity and the time of secular cooling. If the square root of the product of conductivity and age be increased any number of times and the depth also be increased the same number of times, temperature remains unchanged if the initial excess is unchanged, but if the initial excess changes, temperature will change in the same ratio.

Upon the chart are delineated two families of temperature distributions. Those in continuous lines, lettered *a* to *f*, are calculated in accordance with the maximum surface rate of 50·6 ft. to 1° Fahr., being the generally accepted rate at the time Kelvin's curve was published. Those in dotted line and lettered *g* to *i*, are constructed for the rate of 75 ft. to 1° Fahr. the smallest of the observed inland rates. It is the value given by Hallock* for the recently completed boring near Wheeling, W. Va. The last published value as reduced from all available data by the B. A. committee is 64 feet to 1° Fahr. It is, therefore, extremely probable that unless some general but unrecognized cause, like a variation of temperature due to the chemical action of hot water and progressive downward either with heat or pressure, tends to raise or lower the mean rate, the true surface distribution falls between the values of 50·6 and 75 ft. per ° Fahr. upon which the two families of gradients are based.

The diabase line for melting temperature and depth D D is traced from its superficial fusion point, 1,170° C., downward according to the law established by Dr. Barus and expressed in table 5. This is the special point of interest in the chart and in the conclusions to which it gives rise. In passing from this surface value of 1,170° C. through ·1 of the radius, the fusion temperature is raised to 6,139° C.; continuing thence to the center of the earth it reaches the surprising value of 76,200° C. In consequence in an earth all of diabase any temperature gradient having an initial excess of less than the above central value must in reaching the surface either intersect the line D D twice or fall wholly beneath it. Since this line represents melting temperature, any point vertically above it in the chart is necessarily more highly heated than the melting temperature for the same depth, and hence in fusion. Conversely, any point below the diabase line being below the melting temperature for that pressure and depth, falls into solidity. Thus

* This Journal, vol. xliii, p. 234, 1892.

the chart is divided into two areas by the line, that above it representing fluidity, and that below, solidity. For a diabase earth to have been wholly melted an initial excess of 76,200° C. would be required. Obviously any earth having an initial excess of less than the surface melting point 1,170° C. would have been always completely solid. Any initial excess above that figure and below 76,200° C. requires at the moment before refrigeration began, a solid nucleus and a fused zone above it extending to the surface, and the lower the initial excess the larger the solid nucleus of compression and shallower the initial couche of surface fusion. Knowing the law of the rise of the fusion-point it is a simple matter of computation to determine, for any assumed initial excess, exactly the radial value of the original solid nucleus and of the original supernatant fluid couche. For the region covered by the chart these values may be directly scaled off.

Fourier's equation enables us to go further and assuming that refrigeration is the result of conduction alone to determine the temperature distribution for any given period of refrigeration, and what is of particular geological interest the rate at which the fused couche is encroached upon by an overlying superficial crust of congelation, and the existence, depth, temperature and pressure differences of any residual fluid couche between the upper and lower solids. The relation, therefore, of any temperature gradient to the diabase line offers an immediate test of its admissibility as a probable case. Any temperature gradient that in passing across the area of the chart from below to the surface intersects the diabase line must in reaching the low temperatures of the surface intersect it again, and the zone included between the pair of points of intersection being above the line, and hence for that interval of radius above the fusion temperatures, must be a melted shell, and as on the criterion of solidity the existence of any considerable fusion is precluded, such a case of temperature distribution may be rejected.

I will now trace the several temperature distributions upon the chart, and note their relations to time and solidity, beginning with the family delineated in continuous lines (surface rate 50·6 ft. to 1° Fahr.). Line *b*, the gradient of Kelvin, 3,900° C. initial excess, 100×10^6 years secular cooling, is seen to enter the chart from the lower regions, maintaining even to the shallow depth of 226 miles from the surface, practically, its original maximum temperature. From the center of the earth up to this point it has remained in the initial solid of compression. At the depth noted it intersects the diabase line and passes into fusion. Since almost the full initial temperature is maintained up to its intersection,

it follows that that depth nearly marks the original surface of the solid nucleus and that the distance of 226 miles thence to the surface measures the depth of the original couche of fusion. Following the gradient toward the surface it is seen after describing its great convexity in the fluid region to intersect the diabase line a second time and enter a congealed shell or crust formed by cooling a surface portion of the initial fused couche, and leaving between the nucleus and crust, a residual present shell of fusion of 200 miles from top to bottom. The obvious tidal instability of a 26-mile crust resting upon 200 miles of truly fluid magma is sufficient basis for the rejection of this particular case of temperature distribution. To fulfill the requirements of rigidity either the time of cooling must be vastly greater to admit of entire congelation, or the initial excess materially less.

As an illustration of the first of these alternatives, gradient *c* with the same initial excess as *b* (3900° C.) has been developed to complete solidity which on computation proves to have required about 600×10^6 years, at which time it has but just reached tangency with the diabase line. Yet we are absolutely precluded from accepting it as a probable case and assigning 600×10^6 years as the age of the earth, because the temperature values of its emergence at the surface fall below even the 75 feet to 1° Fahr. surface rate. Its emergence is at a rate of ·0081° Fahr. per ft. (124 ft. per ° Fahr.) which is far less than the (Hallock) rate used in the dotted gradients, itself much less than the accepted mean rate of the British Association Committee.

Gradient *d*, 1,950° C. initial excess, and 15×10^6 years secular cooling, falls still some millions of years short of solidity. The initially fused surface couche was about 66 miles in depth, the present crust 33 miles thick and the present residual fluidity of 33 miles depth from top to bottom. Here again the liquid zone involves tidal instability and requires the rejection of the line.

Gradient *e* offers more satisfactory conditions: with an initial excess of 1,750° C., about the normal melting point of platinum, and an age of 20×10^6 years, a condition is reached which throws the convexity of the gradient below the diabase line in complete solidity and fulfills all the conditions. Here then is a possible age for an earth of diabase. Its initial surface couche of fusion would have been about 53 miles and is now wholly cooled into solid crust and united with the original solid nucleus of compression.

Gradient *f*, initial excess 1,230° C. and 10×10^6 years secular cooling, would in its first stage have shown only about five or six miles of surface fusion which would very shortly have cooled into solidity.

For those whose interest centers in earths of great age and high temperature, gradient *a* is given, initial excess 7,800° C. and 400x10⁶ years secular cooling. This has not been projected to the deep, but would not reach solidity until over 1,500x10⁶ years, a truly uniformitarian specimen.

Turning now to the family of three gradients in dotted line, computed to conform to the surface rate of 75 feet to 1° Fahr., the first, *g* is seen to be of the same initial excess as the Kelvin 3,900° C. line. In spite of its long cooling even after 237x10⁶ years it is still very far from solidity. Of the original fluid couche of 226 miles, only about 60 miles has been congealed into crust, 166 miles remaining fused.

Gradient *h*, initial excess 2,560° C., and a 100x10⁶ years refrigeration has an original fluid couche of 120 miles with a present crust of 56 miles and an existing residual couche of fusion of 64 miles, a case also inadmissible from the point of view of instability.

Gradient *i*, initial excess 1,760° C. (platinum melting point), and 46x10⁶ years of cooling, had originally a 53-mile surface couche of fusion which has long since passed into solidity. The following table sums up the condition of all the gradients as to initial excess, initial depth of surface fusion, time of cooling, thickness of crust congealed and present residual couche of fusion.

TABLE 6.—LIQUID SOLID CONDITIONS FOR DIABASE EARTH.

A.—Gradients having the surface rate of 50·6 to 1° Fahr.

Initial excess.	Initial depth of surface fusion.	Time of cooling.	Thickness of crust congealed.	Residual couche of fusion.
° C.	Miles.	Years.	Miles.	Miles.
3900	226	100x10⁶	26	200
1950	66	15x10⁶	32	33
1741	53	20x10⁶	crust and nucleus united	0
1230	6	10x10⁶	" "	0

B.—Gradients having the surface rate of 75 feet to 1° Fahr.

3900	226	237x10⁶	50	166
2560	120	100x10⁶	56	64
1741	53	46x10⁶	crust and nucleus united	0

Comparison of gradients of equal initial excess and successively longer periods of secular cooling shows the ratio of their retreat from right to left across the chart or from lower to higher values of depth and time.

With each augmentation of age the initial tangent defining the surface rate is seen to have declined further and further from the original rate ∞, coinciding with and passing first

the maximum, then the minimum rate thence declining into the region of inadmissible rates.

The probable conditions of the true gradient are as to initial excess and age such as fall below the diabase line into solidity and emerge at the surface with a rate which has not declined below the mean (B A) rate of 64 ft. to 1° F. From the point of view of solidity no gradient of initial excess above 2,000° C. is admissible: that of 2,560° C., even after 100×10^6 years cooling still shows a deep shell of fusion (sixty-four miles from top to bottom), and since it emerges on the minimum rate it has already fallen below the admissible tangent.

Gradient *d*, 1,950° C. and 15×10^6 years, just cooled to the maximum surface rate has still an inadmissible fluid shell, but if refrigeration had been continued for 7×10^6 to 9×10^6 years more the line would have fallen below the solidity line and its surface rate would not have passed the mean value. Hence a 1,950° 24×10^6 year earth is possible and marks about the superior limit admissible for initial excess.

From the point of view of age no greater time of cooling is allowable than enough to bring the gradient for any initial excess to the mean surface rate. Thus the condition for excess and age exclude a line of over 2,000° C. and 24×10^6 years. Conductivity remaining of the value used, any higher excess involves fluidity, and any greater age an inadmissible surface rate.

To the extent, therefore, that solidity is a valid criterion and so far as the melting temperature of diabase may be supposed to apply to the depth examined, there is no escape from an earth of the low age and temperature given except by impugning the rate of surface augmentation and the value of rock conductivity here employed.

Whoever has examined the B. A. committee's reports and summaries on underground temperatures must have realized the obstacles to the evaluation of a true mean rate. The range of observations is wide, from high rates due to residual vulcanism to low ones produced by neighboring bodies of cold water, such as are described by Wheeler from mines near Lake Superior.* It is not, however, likely that by rejecting anomalies and assigning probable weight to further observations the present value will be moved to an important extent.

We have seen that all probable distributions of earth-temperature involve in the initial stage a great solid nucleus, practically the whole body of the earth, with a shallow surface shell of fusion. In the case of the 1,741° C., 20×10^6 year earth there was an initial melted shell of 53 miles. Obvi-

* This Journal, vol. xxxii, 1886.

ously it cannot be correct to apply the rock-conductivity value obtained at air temperatures and normal pressure to even so young and cool an earth with its couche of an initial temperature of 1,741° C. and a pressure difference between the top and bottom of 22,000 atm. The probable method of cooling the couche into solidity, involves three corrections of the accepted rate of refrigeration: *a*, acceleration of the process by possible convection; *b*, the direct effect of heat and pressure upon conductivity, and *c*, the relative conductivity of matter at the same temperature, liquid and solid.

a. Convection. Leaving out of present consideration possible polymerization of the magma, or the descent of solid bodies of crust, vertical transfers of the liquid matter in the fused couche depend upon differences of density and this upon the ratio of the rates at which density is raised by pressure and lowered by heat. Isometrics of melted rock under high pressure are of course beyond the reach of experimentation, hence we are forced to look to those of the available materials. Isometrics from high pressure observations have been found to slope as follows:

Ether	8·7	atm.	per ° C.
Alcohol	10·5	"	"
Thymol	13·9	"	"
Dyphenylamine	15·4	"	"
Paratoluidine	13·9	"	"
Glass, computed	10·0	"	"

Since ether boils at 34° C. and dyphenylamine at 310° C., the range here given is wide. It is reasonable, therefore, to take the mean value, 12·5 atm. per ° C., as an index of the slope sought for. In the Kelvin earth this rate occurs between ·010 and ·015 of radius, the crust being ·0065 of radius thick. In so far, therefore, as the isometrics can be regarded as parallel straight lines with a slope of the order of the value given above, convection can only have taken place in the first 52 miles of the initial couche of fusion and in the present residual couche of 200 miles only the upper 26 miles would be subject to convection. In younger earths the above value per ° C. will be found much nearer the surface so that in them convection would be confined to a shell which is shallow in proportion as the earth is young. Initially when the whole earth was at one temperature there could have been no convection, since the change of temperature in depth was *nil*, but the change of density due to pressure was always pronounced. In the case of the 1,741° C. earth the zone of convection would have early been covered and extinguished

by the thickening crust and therefore would have played no very important part in accelerating the loss of heat, and thus for this particular initial excess is of small effect in shortening the estimate of earth's age.

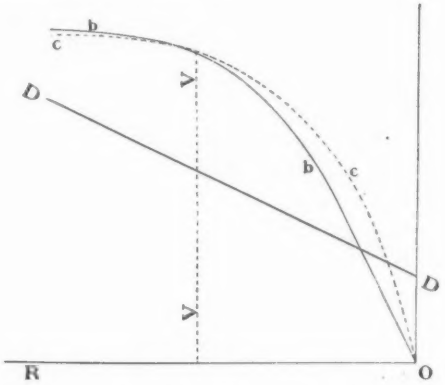
b. The direct effects of heat and pressure upon the conductivity of matter under such high temperatures and pressures are also beyond laboratory investigation, and again we are driven to use the determined conductivity value unmodified, or seek for some other property which may be considered as its approximate measure. Such an index is found in viscosity which if not of high quantitative significance in defining the changing values of terrestrial conductivity in depth, nevertheless affords data applicable at least for determining the sign of an important correction.

Dr. Barus has lately determined that at least 200 atmospheres of pressure are required per one degree Centigrade in order that viscosity may remain constant. Examining several temperature distributions of the chart and applying the computed augmentation of earth-pressure, it appears that the required relation (200 atm. to 1° C.) is found at successively lower depths for successively higher values of initial excess and age. In the 1741° C. case the relation after 20×10^6 years' cooling is found at about ·016 of radius counting from the surface, where the vertical broken line *v. v.* of the chart intersects the gradient and marks the locus of stationary viscosity. As above this point temperature relatively to pressure has augmented more rapidly than the ratio required for constant viscosity it follows that viscosity has been diminished by temperature more than it has been raised by pressure. Below the stationary point, on the other hand, an excess of pressure above the required ratio is available for increase of viscosity.

For the gradient of 3900° C. excess the transitional depth is indicated by the intersection of the broken line V V. In both cases the transitional points occupy positions in their respective gradients not far below their full initial temperatures, and pressure having been most stationary the transitional points have moved but little during the whole period of secular cooling, and the earth shells passing through them have divided radius into a lower solid of higher viscosity and a surface couche, partly liquid partly solid of lower viscosity. So far therefore as viscosity indicates the behavior of conductivity, that also should have been systematically diminished (relatively to the surface value obtained at normal pressure and temperatures and used in the construction of the gradients) from the surface downward for a small fraction of radius, till at the appropriate depth for each excess and age of cooling, it reaches a transitional value and thence increases.

How this correction, of at present unknown value, affects the coördinates of a given gradient qualitatively, is shown by the following figure in which are given the diabase melting point and pressure line, D D, gradient *b* of 3900° C. excess and 100×10^6 year's cooling, with the viscosity transitional line V V intersecting it, also a dotted line *c*, indicating the position of the *b* gradient corrected for diminished conductivity (viscosity).

Lagging to the right of the uncorrected gradient obviously the dotted line would require longer refrigeration to reach the state of solidity, and it is equally important to note that its position requires its emergence at the surface with a higher rate than the uncorrected line and thus extends the time of cooling down to the mean rate which marks for all gradients the present limit of the process.



c. Liquid-solid conductivity. Closely involved in the above heat-pressure-viscosity correction is the change of conductivity on passing isothermally from solid to liquid. Here again the results of Dr. Barus* throw important light.

The relatively higher thermometric conductivity of the solid over the liquid of equal temperature indicates an additional plus correction for time values.

Both the minus correction due to convection, and the plus corrections based upon conductivity diminished below the Everett figures, sink in importance as we pass from earths of higher to those of lower initial excess, so that until some approximate quantitative values can be given them we have no warrant for extending the earth's age beyond 24 millions of years.

* The change of heat conductivity on passing isothermally from solid to liquid. C. Barus, this Journal, July, 1892.

That the application of the criterion of solidity here made to Kelvin's method is open to the objection of being based on the physical relations of an extremely superficial fraction of radius is obviously true. Ignorance of the deeper, interior distribution of specific materials and of their relations to the degree of heat and the range of pressure to which they are subjected, forbids the construction of a generalized line of melting temperatures for the whole of radius.

It might, therefore, be contended that a reversal of the diabase conditions is possible, and the deeper materials may possess the property of ice-fusion; their melting temperatures suffering depression instead of elevation. The high densities required in lower earth-depths have constantly suggested the concentration there of heavy metals and the examples of meteorites has further influenced the idea of a metallic nucleus chiefly of iron. And as iron at normal pressure unmistakably exhibits ice-fusion, any great iron mass at the center might be supposed to exist as a liquid in spite of the enormous pressure there exerted.

The distribution of materials and of "state" under this assumption involves a metallic (iron) nucleus, liquid from ice-fusion, overlaid by less dense couches which at some unassignable depth pass into silicates of the diabase type, solid from compression under the law shown for diabase, and solid to the surface as required by tidal effective rigidity.

Ice-fusion, however, is an exceptional phenomenon, nor have we any but the most limited data as to its range as regards temperature and pressure. Iron is conceded to contract in the act of fusion, but cold iron is more dense than the substance either just above or just below the fusion point. It is not beyond the range of probability that excessive pressures might bring about the same density in iron that cooling does, and thus isothermally convert ice-fusion into the normal type and produce a solid nucleus. However that may be, tidal effective rigidity excludes fusion of either type for at least ·2 of radius.

Other methods have been used for obtaining a measure of the earth's age or for some definite portion of geological time.

Earth-Age from Tidal Retardation.

Kelvin's comparison of the earth's present figure with that of a thousand millions of years ago when the terrestrial day would have been only half its present length is one of the most interesting. The earth, if then plastic, would have yielded to four times the present centrifugal force at the equator and shown a correspondingly greater flattening at the poles

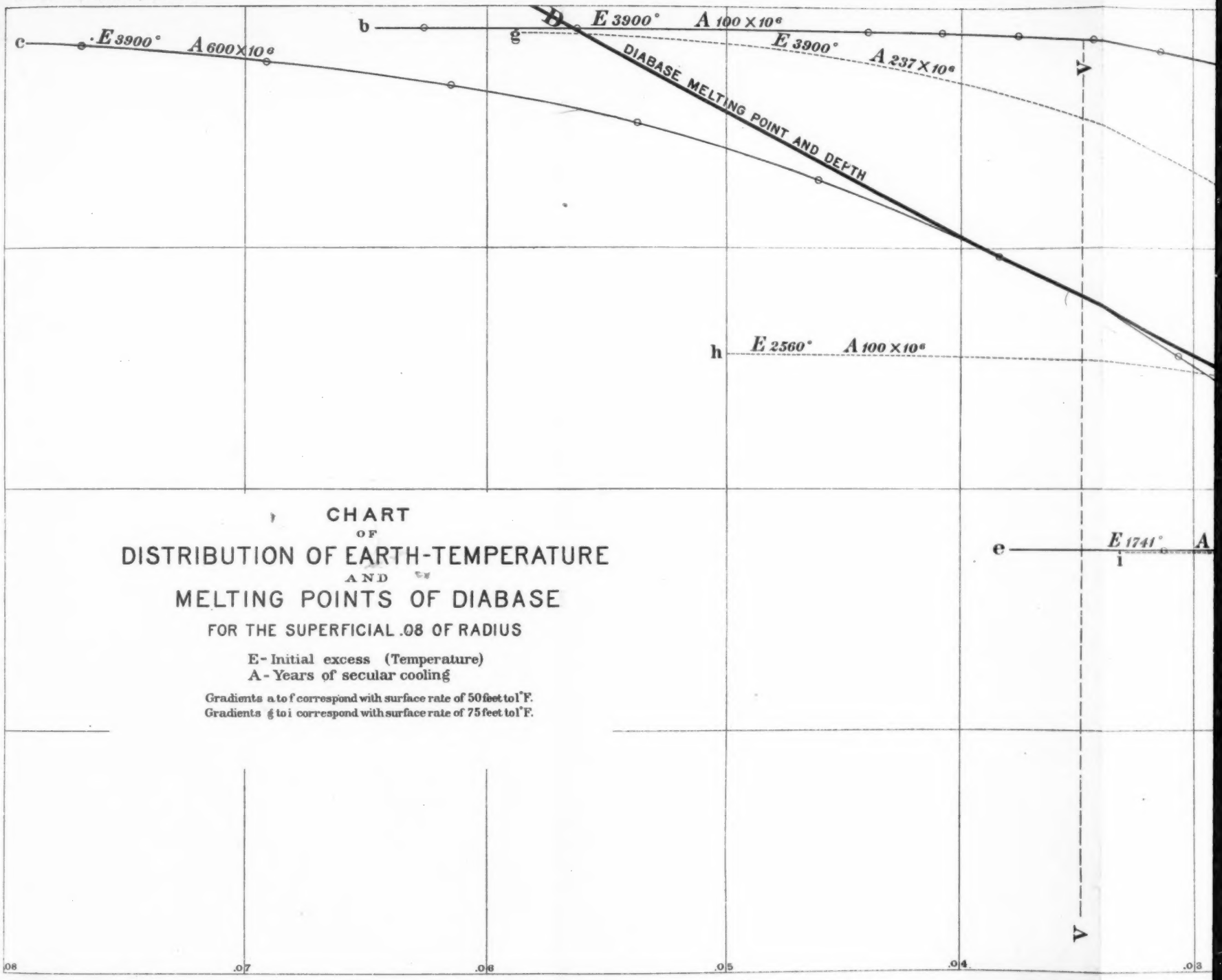


CHART
OF
DISTRIBUTION OF EARTH-TEMPERATURE
AND
MELTING POINTS OF DIABASE
FOR THE SUPERFICIAL .08 OF RADIUS

E - Initial excess (Temperature)
A - Years of secular cooling

Gradients a to f correspond with surface rate of 50 feet to 1°F.
Gradients g to i correspond with surface rate of 75 feet to 1°F.

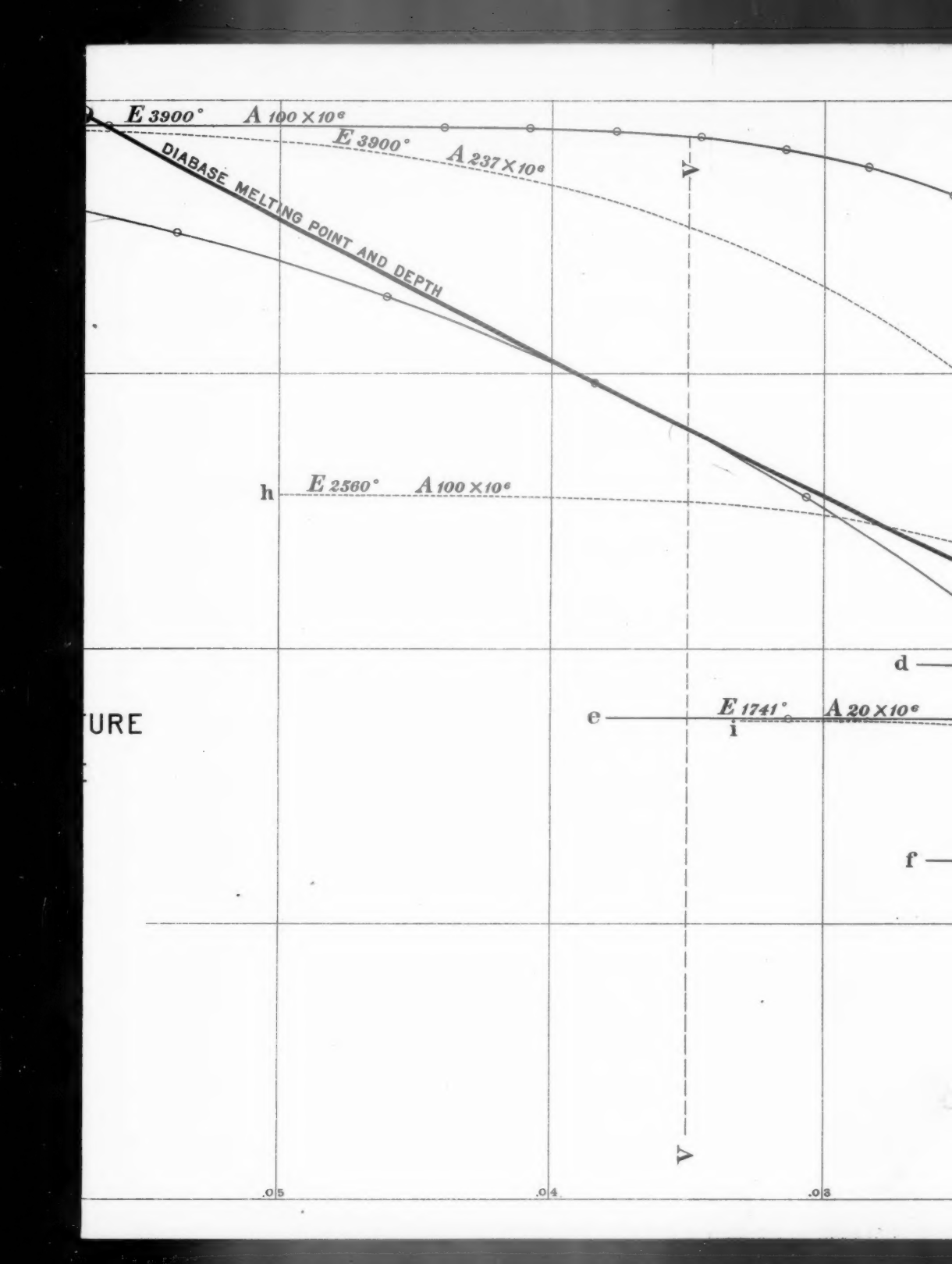

E 3900° A 100 × 10⁶
E 3900° A 237 × 10⁶
DIABASE MELTING POINT AND DEPTH
h
E 2560° A 100 × 10⁶
d
e
E 1741° A 20 × 10⁶
i
f
URE
.05
.04
.03

Plate II.

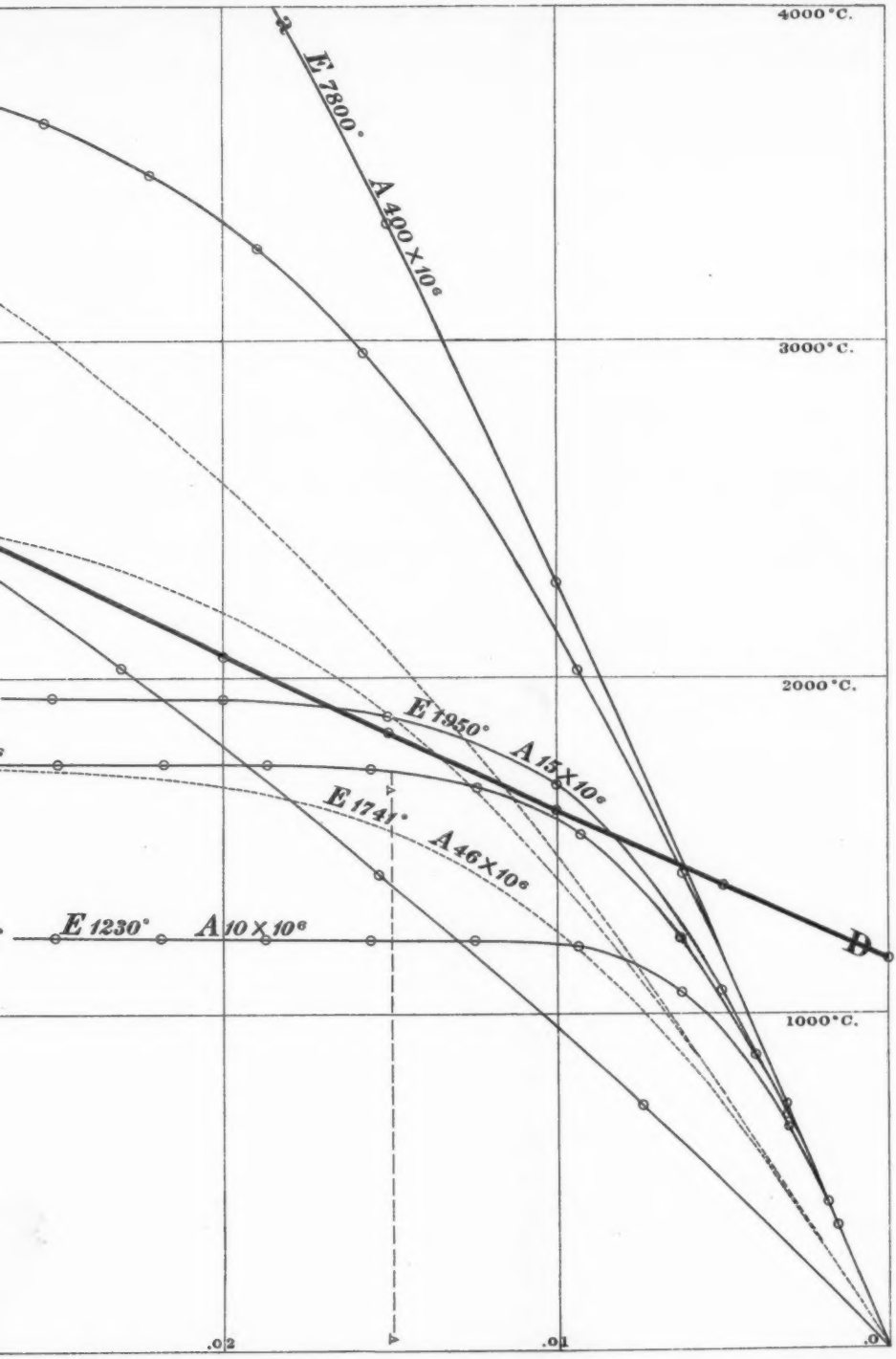
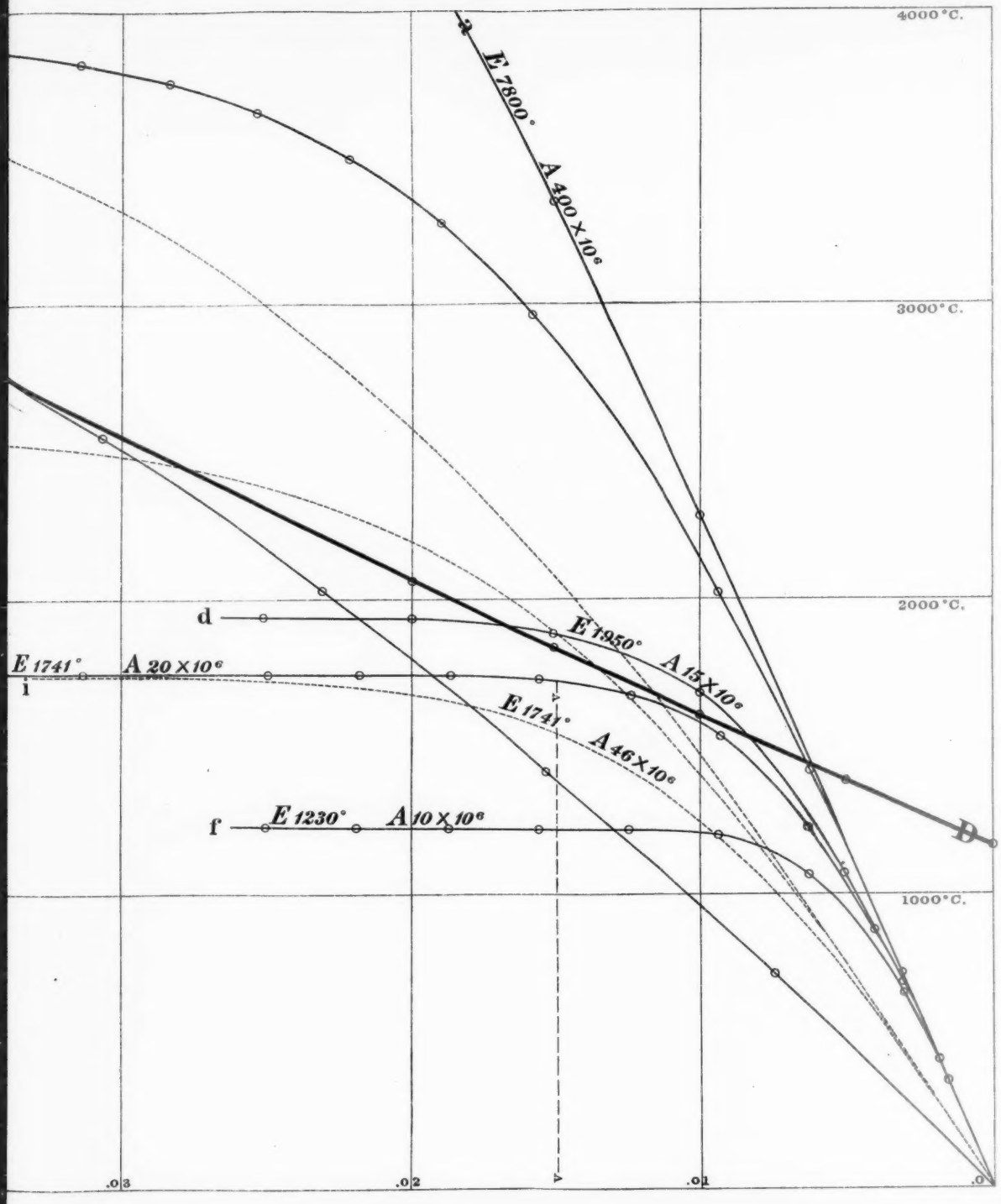

4000°C.
3000°C.
2000°C.
1000°C.
E 7800°
A 400 × 10⁶
E 1950°
A 15 × 10⁶
E 1741°
A 46 × 10⁶
E 1230°
A 10 × 10⁶
D
.02
.01
.0

Plate II.


4000°C.
3000°C.
2000°C.
1000°C.
a
E 7800°
A 400 × 10⁶
d
E 1950°
A 15 × 10⁶
E 1741°
A 20 × 10⁶
1
E 1741°
A 46 × 10⁶
f
E 1230°
A 10 × 10⁶
D
.03
.02
.01
.0

and bulging at the equator and "therefore" (as Tait expresses it) "as its rate of rotation is undoubtedly becoming slower and slower it cannot have been many millions of years back when it became solid, else it would have solidified very much flatter than we find it." This implies that because a computed earlier and greater value of ellipticity does not now exist it could never have existed, in other words, that terrestrial rigidity has been and is of such value that a form taken in the remote past by the solid earth would not be modified by the tidal retardation of rotation and its attendant change of centrifugal force.

There is in modern geology a growing body of evidence which is believed to prove the very general plasticity of the lithosphere, by which it may experience important deformations from very *slowly* applied stresses. So strongly has this belief taken root that many American geologists accept "isostasy" and consider it to be an expression of a fluid equilibrium for the earth.

From abundant geological observation plasticity must be admitted for slow deformations enormously in excess of the small change of figure which the stress of tidal attraction would produce but for elastic resistance.

Although rigidity prevents a sudden tidal deformation of five feet it does not prevent a slow radial deformation of five miles of the surface matter. How then can it be supposed to resist the slow change of stress due to tidal retardation of rotation? The excess of the equatorial over the polar axis is now roughly 25 miles while the radial range of surface inequalities of the lithosphere is about 12 miles, of which a large part dates from this side of the beginning of Tertiary time. If past plasticity equals present values, the earth's figure could never have been a survival from some assumed earlier epoch when centrifugal force was greater, but must always have been a function of the slowly diminishing rate of rotation.

If the conclusions of the earlier portion of this paper are true they go further and exclude the idea of a formerly fluid earth and *any* epoch of solidification. With any admissible assumption of initial excess nearly the whole earth must have been solid from the date of the first collocation of its matter.

To whatever radial depth plasticity may descend, what is enough for geologically recent superficial inequalities is sufficient for adjusting the figure of the earth to existing forces of rotation.

The same coast lines which remain stationary under tidal stress are slowly rising and falling in a hundred places under the slow application of subterranean energy.

It therefore appears that no time measure can be deduced from the supposed fixing of the present ellipticity at some past date.

Astronomical Measure of Earth-Time.

Croll's hypothesis from which it was proposed to fix dates by secular variations of eccentricity and to correlate the *climatic* effects of those variations with geological operations and thus measure certain intervals of geological time, required so much questionable physical geography and left so many physical doubts that few have been found to accept the excessively complex chain of effects lying between eccentricity data and geological facts. The objections of Professor Newcomb, noticed rather than answered, left Croll's doctrine where it was permissible to believe that there was *something* in it, but not necessarily that definite sequence of climates which is the core of the idea.

The gap in Croll's scheme seems to have been successfully stopped by Sir Robert Ball whose interesting proof of the seasonal inequality of the thermal element in climate due to position of the equinoxes, and its intensification in periods of high eccentricity offers a new hope for the accurate dating of at least very modern geological climates. From this point of view late geological history requires reëxamination, and if it should appear that a sequence of climates has existed closely paralleling the thermal variations which the astronomical values seem to afford, an extremely probable case will have been made out. And this case would be practically substantiated if the hypothesis of H. Blytt should yield the confirmation for which he hopes. Blytt* proposes and has already attempted to correlate the secular *attractional* changes due to varying eccentricity and precession with the observed successive shifting of beach lines.

So far as he has proceeded it is of interest to note that his time estimates are more in harmony with the physical than the stratigraphical figures.

Periodic changes in the figure of the hydrosphere relatively to the solid earth, due to alterations of attraction, might be predicted with some confidence if it were clear that the lithosphere would under the slow stresses involved continue to exercise a degree of rigid resistance comparable with that it opposes to the tidal stress, but there is no proof that it would.

Since we find the solid earth undergoing slow deformations to-day which are relatively permanent, while its effective

* The probable cause of the displacement of beach lines. H. Blytt—1889, Christiania Videnskabs Forhandlinger No. 1 — Additional note 1889 — second additional note 1889.

elastic resistance to tidal stress is sufficient to permit a water tide, it appears that either the purely telluric stresses are greater than the moon's attraction, or that there is for the time rate of application of equal stress, a transitional value above which the elastic resistance of the earth-solid is enough to conserve figure, and below which plastic deformation is easy; a relation of properties such as Kelvin suggests for ether. Under the former alternative, deformations due to purely telluric forces might by upheaval or subsidence at any time mask or counteract astronomical beach shifting. In the latter case to make use of the astronomical data for displacement of beaches, it is required to ascertain the time rate of terrestrial plasticity accurately enough to know that relatively to the duration of eccentricity and precession cycles and their correlative attractional variations, the reaction of the lithosphere would differ enough from that of the hydrosphere to allow of the beach shifting sought.

Beyond the most modern geological dates the grander earth deformations have carried ancient beach lines out of all recognizable radial relations with each other and the several oceans of which they mark the shores, or else as is frequently the case with rising continents they have been wholly effaced by erosion. Evidently the Croll-Blytt time measure, interesting as it may prove to be for recent dates, is at present inapplicable to any general determination of the earth's age.

Earth-age measured by Sun-age.

Since the incrustment of the earth would be almost immediately followed by a climate controlled wholly by the sun's heat, redistribution of the crust by water necessitates a sun heat received upon the earth's surface sufficient at least to maintain the temperature above that of permanent freezing.

Newcomb* remarks:

"If we reflect that a diminution of the solar heat by less than one-fourth its amount would probably mean an earth so cold that all the water on its surface would freeze, while an increase of much more than one-half would probably boil all the water away, it must be admitted that the balance of cause which would result in the sun radiating heat just fast enough to preserve the earth in its present state has probably not existed more than 10,000,000 years."

All we know of the earlier strata indicates a water mechanism for the denudation, comminution and deposition of rock. Exactly the division of this work between tidal and river

* Popular Astronomy, p. 511.

forces we may never know, but all evidences confirm the conviction that life was continuous from its earliest, or at least an early, appearance and hence climate must have been continuously suitable for the circulation of continental waters. The range of temperature for the time since the beginning of the Huronian must have been well within Newcomb's limits. So that unless the selective absorption of either the sun's atmosphere or the earth's or both have varied reciprocally or concurrently with radiation, solar emission cannot have had a wide range of either secular or paroxysmal change.

Nevertheless the age assigned to the sun by Helmholtz and Kelvin (15×10^6 or 20×10^6 years) communicated a shock from which geologists have never recovered. The thermodynamic reasoning on which the brevity of the sun's life is reached stands undisturbed, yet so powerful is the influence of the old uniformation method of estimating the age of the total stratified crust, that to many geologists it has seemed easier to reject the physical conclusions than to seek a source of error in our own very vulnerable methods.

If as I hold, Kelvin's suggestions as to ellipticity and tidal retardation do not apply to an earth readily deformable by slow stress as this one evidently is, there remain but three earth-ages to be weighed—Kelvir's value from terrestrial refrigeration which this paper seeks to advance to a new precision, Helmholtz and Kelvin's age of the sun which must sharply limit the date of the redistributed earth crust, and the old stratigraphical method. From this point of view the conclusions of the earlier part of this paper become of interest. The earth's age, about twenty-four millions of years, accords with the fifteen or twenty millions found for the sun.

In so far as future investigation shall prove a secular augmentation of the sun's emission from early to present time in conformity with Lane's law, his age may be lengthened, and further study of terrestrial conductivity will probably extend that of the earth.

Yet the concordance of results between the ages of sun and earth, certainly strengthens the physical case and throws the burden of proof upon those who hold to the vaguely vast age, derived from sedimentary geology.

ART. II.—*The Tertiary Geology of Calvert Cliffs, Maryland;** by GILBERT D. HARRIS, Washington, D. C.

(Communicated by permission of the Director of the U. S. Geological Survey.)

ON the Bay shore of Calvert county, Maryland, extends a long series of high cliffs, remarkable for their abruptness and continuity. Here and there, to be sure, occur narrow channels of bayward flowing streams, but extensive stretches of lowlands are wanting. It therefore becomes possible to trace every important stratum represented in these cliffs from its northernmost outcrop to where its southern dip carries it beneath tide level. This task has actually been attempted; and the series of sections given in the map, p. 23, shows diagramatically some of the results obtained.

Herring bay, Section 1.—This locality is somewhat north of Calvert cliffs proper, and the horizon of its fossiliferous exposure has not been definitely correlated with those farther south; yet on paleontologic grounds alone, it is safe to say that the lower portion of Section 1 is stratigraphically equivalent to, or somewhat below *Zone a* of Sections 2 and 3.

Conrad† mentions from this locality:

Bones of Cetacea, siliceous casts of marine shells, Ostrea percrassa, Pecten Humphreysii.

The present writer's list includes:

Ostrea percrassa, Pecten Humphreysii, Pecten madisonius, Striarca centenaria, Thracia Conradi?, Carditamera arata, Lucina subplanata, Crassatella melina, Corbula elevata, Astarte varians, siliceous casts of a Turritella, probably T. Mortoni from neighboring Eocene deposits, Discina lugubris.

These fossils consist of casts only, and are found in the lower 10 feet of Section 1. The matrix is a bluish green sandy clay. Above lie variable thicknesses of diatomaceous earth, sand, and clay, all of a light yellowish hue, rarely containing molluscan remains, though small *Nuculidæ* were in one instance seen at an elevation of 30 feet above the level of the Bay.

Section 2.—About one mile south of Fishing creek the following section occurs:

*The field observations upon which this essay is based were made under the auspices of the U. S. Geological Survey, April 23–30, 1891, and May 23–June 1, 1892. During the latter period, the writer was accompanied by Mr. Frank Burns, whose diligence and skill at collecting very materially aided in procuring the results here presented.

† Proceed. Nat. Inst., 2d Bull., 1842, p. 181.

No. 1.	Light yellowish sand	5 feet.
2.	Light clay, brownish above	5 "
3.	Isocardia layer	2 inches.
4.	Bluish clay with Lucina subplanata	2 feet.
5.	Ostrea percrassa bed, greenish sand	6 inches.
6.	Bluish sandy clay	2 feet.

The beds here represented dip slightly to the north. They are cut off by Pleistocene deposits before reaching half way to Fishing creek, so that it is impossible to determine how far northward this abnormal dip extends.

Section 3.—This is the locality described by Conrad as "Colonel Blake's" in the Second Bulletin of the Proceedings of the National Institution, page 181. He says: "The cliff is at least one hundred and fifty feet high. At base we found a clay replete with a species of *Tellina*, probably new, and over this at about six feet elevation, a thin stratum of *Ostrea percrassa*. The upper portion of the cliff consists of sand and clay, and appears to be destitute of organic remains."

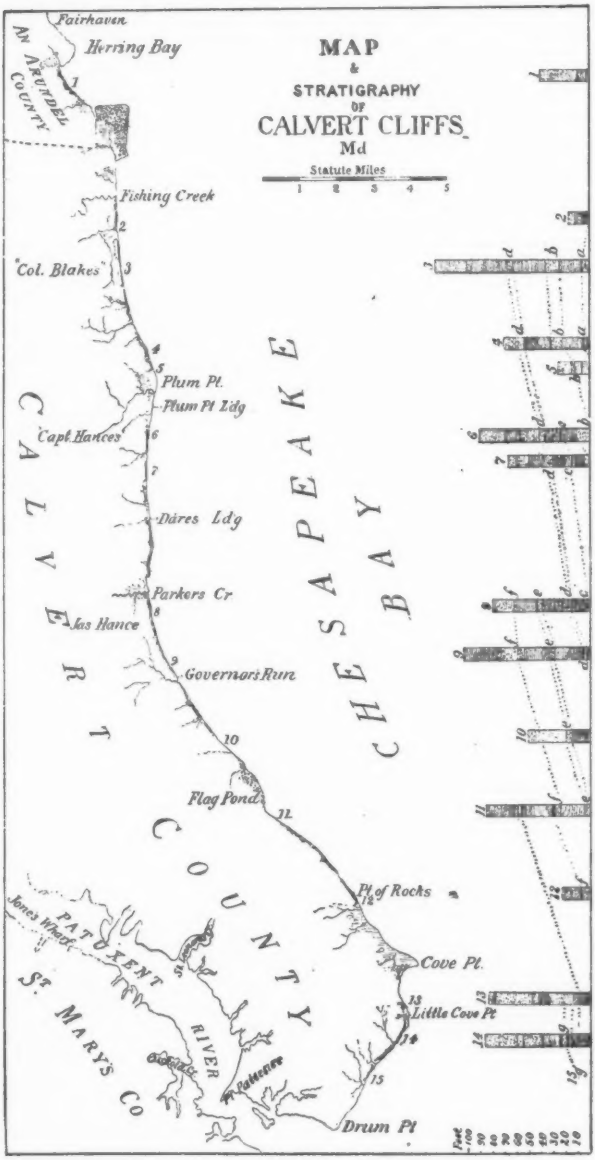
Conrad doubtless examined this locality somewhat hastily, insomuch as several fossiliferous beds occur in the sand and clay regarded by him as "destitute of organic remains."

The section stands thus:

No. 1.	Light colored clayey sand	25 feet.
2.	Sandstone ferruginous layer. (Fossiliferous?)	4 "
3.	Blue clay	10 "
4.	Ferruginous sand. (Fossiliferous?)	3 "
5.	Blue clay	20 "
6.	*Zone d;* Isocardia bed; ferruginous sand	5 "
7.	Bluish sandy clay	15 "
8.	Ferruginous brownish sand	4 "
9.	Blue clay	8 "
10.	*Zone b;* greenish gray fossiliferous sand. This stratum is overlaid by a line of concretions	12 "
11.	Light bluish sandy clay; Corbula layer 3 feet from base	18 "
12.	*Zone a;* Ostrea percrassa, in greenish sand	6 inches.
13.	Gray sandy clay to surface of water	6–8 feet.

From *Zone b*, at this locality, Mr. Burns and the writer obtained the following species:

Pelecypoda.—Pecten madisonius, Arca subrostrata, Pectunculus parilis, Nucula sp. undt., Astarte varians, Crassatella melina, Lucina anodonta, Lucina Foremani, Lucina crenulata, Cardium leptopleura, Isocardia Markoei, Venus latilirata, Venus staminea, Cytherea marylandica var.?, Tellina subreflexa, Corbula idonea, Corbula elevata, Panopæa porrecta?


MAP
&
STRATIGRAPHY
OF
CALVERT CLIFFS
Md
Statute Miles
1 2 3 4 5
Fairhaven
Herring Bay
An Arundel County
Fishing Creek
Col. Blakes
Plum Pt.
Plum Pt Ldg
Capt. Hances
Dares Ldg
Parkers Cr
Jas Hance
Governors Run
Flag Pond
Pt of Rocks
Cove Pt.
Little Cove Pt
Drum Pt
CALVERT COUNTY
CHESAPEAKE BAY
PATUXENT RIVER
St. MARYS CO
Jones Wharf
St Catherine
Feet
100 90 80 70 60 50 40 30 20 10

Gastropoda.—Oliva sp. undt., Voluta typus, Fulgur coronatum, Turritella indenta, Turritella exaltata, Crucibulum contractum, Infundibulum perarmatum.

From *Zone d*, Isocardia n. sp. and Venus n. sp. were obtained.

Section 4.—The bluffs are much lower at this locality, *Zone d* being overlaid by only 10 feet of light barren sand. The southerly dip is here recognizable, but it becomes much greater a little farther south.

Section 5.—In this section, all but the basal three feet of *Zone b* has been removed by erosion, and the space refilled with Pleistocene sand and gravel. From the remnant of this zone the following species were obtained: *Pecten madisonius*, *Arca subrostrata*, *Astarte varians*, *Venus latilirata*, *Dosinia acetabula*, and a smooth *Dentalium*.

Section 6.—The next good exposure seen on the bay shore going south is about one mile below Plum point landing. This is the locality designated as "Captain Hance's" in Conrad's article referred to above. Fossils are here very abundant, but owing to their softness, it is difficult to obtain whole or perfect specimens. The species enumerated in the following table were all obtained from *Zone b* as it crops out along the base of low bluffs a few hundred yards north of Section 6.

Molluscan Species of Zone b, one mile south of Plum Point Landing, Calvert County, Maryland.

Pelecypoda.—Ostrea, sp., Anomia, young, Pecten Humphreysii, Pecten madisonius, Perna maxillata, Pinna muricata ?, Modiola, fragment, Arca subrostrata,* Byssoarca marylandica, Pectunculus parilis, Nucula sp. nov., Leda sp., Leda sp. nov., Cardita granulata, Astarte varians,* Astarte exaltata,* Astarte sp., Crassatella melina,* Lucina subplanata,* Lucina anodonta, Lucina Foremani,* Lucina crenulata,* Lucina sp., Chama congregata, Cardium leptopleura,* Isocardia Markoei,* Isocardia sp. nov., Venus Ducateli var. of mercenaria ?, Venus staminea,* Venus latilirata,* Cytherea marylandica var., Dosinia acetabula,* Tellina subreflexa, Tellina sp., Semele carinata, Mactra sp., Mactra (Schizoderma), Corbula cuneata, Corbula idonea,* Corbula elevata,* Saxicava sp. nov., Pholas ovalis, Panopæa goldfussii ?

Gastropoda.—Actæon fragment, Volvula iota ?, Cylichna sp., Terebra simplex, small var., Pleurotoma marylandica,* Pleurotoma calvertensis ?, Pleurotoma bella-crenata,* Pleurotoma parva, Pleurotoma sp., Cancellaria engonata,* Cancellaria sp., Oliva literata, small, Volutella sp. nov., Scaphella solitaria,* Scaphella typus, Fulgur coronatum, Fusus devexus, Fusus migrans, Ecphora

* Mentioned also by Conrad, pp. 181–182; 2d Bull. Proc Nat. Inst., 1842.

quadricostata, Nassa peralta, small var., Scala pachypleura,* Niso lineata ?*, Pyrula sp. nov., Turritella indenta,* Turritella exaltata,* Turritella plebeia, Solarium trilineatum, Crucibulum constrictum, Crepidula, small sp., Natica heros, Natica duplicata, Sigaretus fragilis,* Calliostoma sp., Infundibulum perarmatum,* Fissurella marylandica.*

Brachiopoda.—Discina acetabula.

In addition to the above forms, Conrad mentions in the Proceedings of the National Institution, *Arca depleura*, *Pectunculus lentiformis*, *Lima papyria*, *Cancellaria biplicifera*, *Dentalium thalloides*, *Voluta mutabilis*, *Marginella perexigua*, and *Trochus peralveatus*. Of these, *Pectunculus lentiformis* and *Voluta mutabilis* were afterwards called by Conrad himself, *P. parilis*, and *V. typus*. The name *Dentalium thalloides* had been applied by this author nine years before to a characteristic Claiborne species.

Section 6, may be subdivided as follows:

No. 1.	White sandy clay	15 feet.
2.	Light clay with conchoidal fracture	12 "
3.	Yellowish sandy clay	16 "
4.	*Zone d ;* Isocardia bed ; Yellowish sands	8 "
5.	Bluish sandy clay	14 "
6.	*Zone c ;* thin seam of Venus sp. nov. and sand	6 inches.
7.	Clayey sand ; bluish above, becoming brownish below	15 feet.
8.	*Zone b ;* greenish gray sands	8 "

The *Isocardia* of *Zone d* is quite different from *I. fraterna*, as well as from *I. rustica*. It is smaller, not so large posteriorly, and with differently formed teeth. The new species of *Venus* which characterizes *Zone c*, bears some resemblance to *V. penita*. The same, or a very closely allied species was found by the writer about 1½ miles southeast of Skipton, Talbot county, on the "Eastern shore" of Maryland.

Section 7.—This section presents no very remarkable features. As seen on map, p. 23, nearly all the component beds of Section 6 are found here from 5 to 8 feet nearer tide level than they are in that section. Before passing on to Section 8, however, it may be remarked that Conrad was doubtless somewhat mistaken in giving "Col. Beckett's" as the location of a fossiliferous outcrop; for the low bluffs all along the old Beckett farm (just above Dare's landing), are made up wholly of Pleistocene sands.

Section 8.—Just below Parker's creek, on land owned by James Hance, steep escarpments occur ranging in height from 40 to 70 feet. In these, *Zones c* and *d* are found much nearer

tide level than in Section 7, while at an elevation of 40 feet, a new fauna makes its appearance (*Zone e*). Here the species of Barker's land on the Choptank, and Jones's wharf on the Patuxent river predominate to the exclusion of those mentioned on page 25 from *Zone b*, of Section 6. Some of the fossils here recognized are: *Pecten madisonius*, *Perna maxillata*, *Mytiloconcha*, *Astarte obruta var.*, *Crassatella turgidula*, *Cardium laqueatum*, *Venus mercenaria*, *Corbula idonea*, *Ecphora quadricostata*, *Turritella plebeia*, etc. For several feet above, in the face of the cliff, no well preserved fossils are seen; but in an old roadway, perhaps 200 yards back from the shore, at an elevation of from 60 to 77 feet Mr. Burns discovered a recurrence of this fauna in a friable, yellow sand matrix. Its position is indicated in Section 8 by the letter *f*. The more abundant and conspicuous fossils from this locality are:

Arca elevata, Carditamera protracta, Astarte obruta, Crassatella marylandica, Crassatella turgidula, Lucina contracta, Lucina anodonta, Mysia acclinis, Cardium laqueatum, Isocardia n. sp., Venus mercenaria var. mortoni, Cytherea marylandica, Dosinia acetabula, Corbula idonea, Panopæa americana, Natica duplicata.

South of Section 8, *Zone f* shows plainly in the face of the cliffs, but is too high to be reached. Large masses, however, are often dislodged by atmospheric agencies and, in falling, crumble to pieces, and afford ample opportunity for examining their fossil contents. In this way *Pecten madisonius*, *Perna maxillata*, *Cytherea sayana? Tellina biplicata*, and "*Petricola*" *centenaria* have been added to the faunal list of *Zone f*.

Section 9.—The following section was taken about two-fifths of a mile north of Governor's Run:

No. 1.	Bluish and yellowish sandy clay	25 feet.
2.	Blue clay (base of Pleistocene?)	5 "
3.	Yellow sand	0–3 "
4.	*Zone f*; yellow fossiliferous sand	15 "
5.	Resembling No. 4, but with few small fossils	4 "
6.	Marly bluish sand	20 "
7.	*Zone e*; Yellowish and grayish fossiliferous sand	4 "
8.	Yellow sand with blue clay bands	15 "
9.	Blue clay	8 "
10.	*Zone d*; Isocardia bed;	3 "
11.	Bluish clayey sand	3 "

Section 10.—The escarpments south of Governor's Run are for some distance obscured by the growth of trees, underbrush, and grasses; but at Section 10, about 2¼ miles south of this

place they are again barren and abrupt, though generally of a very moderate elevation. The beds here exposed are as follows:

No. 1.	Pleistocene yellowish sand	30 feet.
2.	*Zone e;* fossiliferous grayish and yellowish sand	5 "
3.	Bluish sandy clay	15 "

A large collection of the fossils of *Zone e* was here made by Mr. Burns. It includes:

Pelecypoda.—Pecten madisonius, Perna maxillata, Mytilus, large cast perhaps M. incurva, Arca elevata, Astarte obruta, var., Crassatella turgidula, Lucina anodonta, Lucina contracta, Mysia acclinis, Diplodonta sp., Cardium laqueatum, Isocardia rustica Con. (partim) non Sow., Venus mercenaria, var. mortoni, Cytherea marylandica, Dosinia acetabula, "Petricola" centenaria, Tellina biplicata, Corbula idonea, Panopæa porrecta, Panopæa americana.

Gastropoda.—Ecphora quadricostata, Turritella plebeia, Natica heros? Crucibulum sp.

Section 11.—Below Flag pond, high bluffs again set in, and present the following section:

No. 1.	Light sands and clays	25 feet.
2.	Band of Perna, Pecten, etc.	2 "
3.	Bluish sandy clay	25 "
4.	*Zone f;* overlaid by a one foot band of very hard ferruginous fragmentary rock	5 "
5.	Grayish sandy clay	20 "
6.	*Zone e*	5 "

Between this and the next section, *Zones e* and *f* are often wholly made up of huge, unshapely, hard rocks as described by Conrad on page 183 of his article already referred to.

Section 12.—This is the last exposure on the Bay shore before reaching Cove point. *Zone f* is here found at tide level, and is overlaid by about 15 feet of Pleistocene sand.

Section 13.—It is impossible at present to state the exact stratigraphic relations of the various fossiliferous zones occurring south of Cove point with those to the north. Yet the discrepancy here involved is in all probability a matter of not over ten or twenty feet. Above *Zone f* in Section 11 there are bluish clays whose equivalents farther south towards Section 12 become blackish and contain a few organic remains. Among these were noted *Solen ensiformis* a Mactroid shell like a small *Schizoderma delumbis*, and *Nassa peralta*. Section 13 is as follows:

No. 1.	Sand	4 feet.
2.	Light yellowish sand	30 "
3.	Hard ferruginous sand stratum	8 "
4.	Bluish black efflorescent marl	8 "
5.	Light yellowish and bluish sandy clay	25 "
6.	Compact blue clay	9 "

It is believed that the lowest member of this section bears to the dark bluish or black clays above *Zone f*, between Sections 11 and 12 the stratigraphic relation indicated on the map.

After rounding Little Cove point, No. 6 becomes quite fossiliferous and so also does the basal portion of No. 5. Here the section presented is as follows:

No. 1.	Pleistocene sand and gravel	0–5 feet.
2.	Light yellowish sand	5 "
3.	*Zone g*; light sands	3 "
4.	Blue clay	5 "
5.	Fossiliferous sand	1 foot.
6.	Blue clay	4 feet.
7.	Fossiliferous sands	1 foot.
8.	Blue clay	3 feet.

No. 5 contains the following forms all more or less waterworn:

Pelecypoda.—Pecten madisonius, Arca idonea, Cardium laqueatum, Venus mercenaria, Dosinia acetabula, Corbula cuneata.

Gastropoda.—Terebra simplex?, young, Pleurotoma parva, Nassa peralta, Astyris communis, Natica duplicata, Turritella plebeia.

No. 3 or *Zone g* is not very fossiliferous at this particular locality but a few yards farther south is replete with:

Pelecypoda.—Pecten madisonius, Lucina crenulata, Venus mercenaria, small, Cytherea Sayana, Tellina biplicata, Mactra ponderosa, Mactra subcuneata, Solen ensiformis.

Gastropoda.—Actæon ovoides, Terebra simplex, Pleurotoma communis, Nassa integra, Nassa peralta, Turritella plebeia, Pleurotoma parva, Fulgur coronatum, Ecphora quadricostata, Natica duplicata, Natica heros.

Section 14.—In going southward from Little Cove point, the fossiliferous layers exposed in the cliffs are observed to gradually rise and at Section 14 present the following appearance:

No. 1. Yellowish sand ..... 25–40 feet.
2. Hard ferruginous layer ..... 5 "
3. Yellowish sand ..... 15 "
4. Ferruginous layer ..... 1 foot.
5. Light and dark, yellow and blue sandy clay. 15 feet.
6. *Zone g;* grayish sand ..... 4 "
7. Blue clay ..... 4 "
8. Fossiliferous sand ..... 1 foot.
9. Bluish sandy clay ..... 15 feet.

Section 15.—At the southern terminus of the cliffs between Little Cove point and Drum point, *Zone g* is 10 feet above tide, and contains the same fauna as that last mentioned.

The following section is a generalization of all the foregoing sections, taken from 14 to 1 in a descending order. An attempt is moreover made to correlate as far as possible from personal observation the various fossiliferous zones here represented with those farther west on the Patuxent, and those of the "Eastern shore."

No. 1. Yellowish sand ..... 25–40 feet.
2. Hard ferruginous layer. (Fossiliferous?) ... 5 "
3. Yellowish, bluish, or even black sandy clay. 33 "
4. *Zone g* ..... 3–4 "
This together with the two fossiliferous layers, Nos. 6 and 8, contain a typical St. Mary's Miocene fauna.
5. Blue clay ..... 4–5 "
6. Fossiliferous sand ..... 1 foot.
7. Blue clay ..... 4 feet.
8. Fossiliferous sand ..... 1 foot.
9. Blue sandy clay ..... 12 feet +
10. *Zone f;* yellow fossiliferous sand generally, 6–15 "
11. Yellowish and grayish sand, few fossils ... 20–25 "
12. *Zone e;* yellowish or grayish sand ..... 4–8 "
The substance of this bed as well as No. 10, is sometimes highly ferruginous and very hard. Nos. 10 and 12 are intimately related, and represent one faunal horizon. This occurs also at Jones's wharf on the Patuxent, and at Barker's landing on the Choptank river, about five miles southeast of Easton, Md. At Greenborough, Caroline county, very nearly the same horizon is represented, though it may be slightly higher.
13. Light bluish sand and clay, often weathered yellowish ..... 20–25 "
14. *Zone d;* compact bluish or yellowish sandy clay ..... 3–5 " +

15. Bluish sandy clay ..... 14–17 feet.
16. *Zone c;* thin seam of bluish compact sandy clay ..... ½–1 foot.
17. Bluish clay ..... 8–15 feet.
18. *Zone b;* grayish sand ..... 8–12 "
    This horizon crosses the Patuxent near Benedict. On the "Eastern shore" it is well represented in marl pits about ¼ mile south of Skipton.
19. Light bluish sandy clay, with thin layers of Corbula alta, and with casts of Tellina and Yoldia ..... 16–20 "
20. *Zone a;* greenish gray sand, replete with Ostrea percrassa, together with a few specimens of Pecten madisonius and P. Humphreysii ..... 6 inches.
21. Bluish green sandy clay as at Fair Haven.. 15 feet+

Total 203–263 feet+

In this section there are represented three fairly distinct and well defined faunas. These may be enumerated as follows:

1. *The St. Mary's fauna;* characterized by such species as:

Arca idonea, Astarte perplana, Venus alveata, Mactra ponderosa, Mactra subnasuta, Solen ensiformis, Terebra simplex, Conus diluvianus, Pleurotoma communis, Fusus parilis, Fusus rusticus, Bulliopsis integra, Nassa peralta, Murex acuticostata, Scala expansa, Turritella variabilis.

2. *The Jones' wharf fauna;* characterized by such species as:

Mytiloconcha incurva, Arca elevata, Carditamera producta, Astarte obruta, Crassatella turgidula, Mysia acclinis, Cytherea marylandica, Mya producta, Panopæa americana, Turritella terebriformis, Calliostoma Wagneri.

3. *The Plum Point fauna;* characterized by such species as:

Pecten Humphreysi, Arca subrostrata, Byssoarca marylandica, Pectunculus parilis, Astarte varians, Astarte exaltata, Crassatella melina, Lucina Foremani, Cardium leptopleura, Corbula elevata, Isocardia Markoei, Venus staminea, Venus latilirata, Pleurotoma marylandica, Pleurotoma bellacrenata, Scala pachypleura, Turritella indenta, Turritella exaltata, Solarium trilineatum.

In concluding, it may be of interest to make a few brief comparisons between these observations and those of earlier writers.

Conrad,* in 1841, seemed not to detect the true stratigraphy of the fossiliferous deposits he noted along this shore, and strangely enough, apparently believed them to extend nearly horizontally from Fair Haven to Drum point.

In 1880, Heilprin† concluded from a study of the paleontologic literature on the subject, that there must be a southern dip along this shore in so much as two faunas, differing considerably in their relative proportions of recent and extinct species, are here represented. To the older fauna, the species occurring at Fair Haven, "Col. Blake's," "Capt. Hance's," and those from the base of the "Cliff near Beckett's," are referred; to the newer, those from the upper part of the last mentioned cliff as well as those from localities south of Cove point. Had Heilprin examined these sections personally, his conclusions would doubtless have been quite different. The three-foot fossiliferous layer in the upper part of Conrad's section at "Beckett's" is obviously the same as *Zone d* of the present essay, and not the Jones's wharf beds as Heilprin supposed. Nor is it this bed that furnishes the St. Mary's fauna below Cove point: between the two occur at least 70 feet of deposits bearing a well marked fauna.

In Darton's‡ paper on the "Mesozoic and Cenozoic Formations of Eastern Virginia and Maryland," published in 1891, he subdivides the "Chesapeake formation" into three parts, thus: "The lower beds consist mainly of dark-colored clays and fine, mealy sand containing the extensive and well-known diatomaceous deposits. These are succeeded by lighter colored clays and sands, with occasional local inclusions of blue marl. The upper beds are coarse-grained, and consist chiefly of white beach sands containing shells and deposits of shell fragments, and occasional argillaceous members." The outcrops at Herring bay are said to belong to the lower beds; those on the lower St. Mary's river to the medial; and "those along the lower Patuxent river and the adjoining shores of Chesapeake bay," to the upper beds.

* 2d Bull. Proc. Nat. Inst., 1842, p. 176.
† Proceed. Phila. Acad. Nat. Sc., 1880, pp. 23–30.
‡ Bull. Geol. Soc. Am., vol. ii, p. 444.

ART. III.—*On the "Anglesite," associated with Boléite*, No. 55; by F. A. GENTH.

MALLARD and Cumenge state in their interesting investigation on boléite* that anglesite, generally covered with a coating of gypsum, of variable thickness, is associated with the boléite from Boléo, Lower California, Mexico. These crystals showed such a peculiar appearance that I thought they deserved a fuller investigation, for which Mr. Clarence S. Bement with his usual liberality, furnished me with excellent material.

The crystals, from 2 to 20^{mm} in size are often distorted, but show generally a very common form of anglesite, the planes *c*, *m* and *l* predominating. They are opaque, and of a luster, between vitreous and greasy, their color is from white to bluish white, some show minute blue spots from a slight contamination with boléite. Many crystals have a coating of gypsum or minute scales of the latter implanted, while others are entirely free from it. Sp. gr. = 4·401. The material for the analysis was selected with great care and the purest that could be obtained, it gave:

		Molecular ratio.	
$PbSO_4$	76·16	0·251	2
$CaSO_4$	17·31	0·127	1
H_2O	4·53	0·251	2
Boléite by diff.	2·00		
	100·00		

This gives the formula: $2PbSO_4+CaSO_4+2H_2O$. As it is not very likely that 2 mol. of $PbSO_4$ should have crystallized with one mol. of gypsum in exactly the same form as anglesite, we must come to the conclusion, that the so-called anglesite crystals from Boléo are pseudomorphs after a mineral of the composition.: $2PbSO_4 . CaSO_4$, which has not yet been observed in its original condition, but only after the calcium sulphate in it had taken up two molecules of water and changed into gypsum which now forms a mechanical mixture with the remaining anglesite, from which it can be completely extracted by water.

The fine powder of two small crystals was treated with water, as long as any precipitate of calcium oxalate could be formed in the filtrate; a small quantity of lead in the solution was removed by hydrogen sulphide.

* Bull. Soc. Franc. de Mineralogie, December, 1891.

The analysis gave:

$PbSO_4$	74·76
$CaSO_4$	19·64
H_2O required to form gypsum	5·20
	99·60

showing that these crystals had a considerable admixture of gypsum.

Chem. Laboratory. 111 S. 10th St.,
Philadelphia, Nov. 22d, 1892.

ART. IV.—*Preliminary Account of the Iced Bar Base Apparatus of the U. S. Coast and Geodetic Survey;** by R. S. WOODWARD.

Historical Note.—The use of ice in thermometry to furnish a standard temperature naturally suggests the availability of ice to fix the temperature of a standard of length when used in laboratory comparisons or in measuring base lines It does not appear, however, that ice has been generally used even in laboratory work with standards of length,† and I am not aware that any attempt has been made hitherto to measure a base with a bar whose temperature is controlled by means of melting ice. The feasibility of using such an apparatus in base measurement has, nevertheless, been suggested and maintained by several persons. One of the first, if not the first, to outline a scheme for such an apparatus is, I believe, Mr. E. S. Wheeler, a former colleague on the U. S. Lake Survey. Mr. Wheeler's plan is advocated by Professor T. W. Wright in his treatise on the Adjustment of Observations.‡ The late Captain C. O. Boutelle of the U. S. Coast and Geodetic Survey also advocated the use of such apparatus.

Soon after joining the U. S. Coast and Geodetic Survey in July, 1890, I was requested by Dr. Mendenhall, Superintendent, to devise means of testing in the most thorough way

* Communicated by permission of the Superintendent of the Survey. The substance of this paper was presented before Section A of the American Association for Advancement of Science, at the Rochester meeting. August, 1892.

† From published accounts it would appear that the most extensive series of laboratory comparisons of standards, wherein ice was used, are those of the U. S. Lake Survey, conducted under the superintendence of General C B Comstock, Corps Engineers, U. S. A. In these comparisons ice was successfully used during several years. See Professional Papers Corps Engineers, U. S. A , No. 24.

‡ D. Van Nostrand, New York, 1884. See also this Journal, III, vol. xxviii, p. 479.

practicable the efficiency of the various forms of base apparatus used by the Survey and especially the efficiency of long steel tapes or wires. Accordingly, considerable study was given to this subject during the autumn of 1890 and the winter of 1890–1, and the plans and specifications for the iced bar apparatus considered in this paper were matured and approved early in the spring of 1891. It was constructed in Washington, partly by the machinists E. N. Gray and Co., and D. Ballauf, and partly by the Instrument Division of the Survey.

Before proceeding to a description of the apparatus I desire to acknowledge my indebtedness to colleagues of the Survey for valuable suggestions and criticism. I am specially indebted to Mr. John S. Siebert, who verified all of the preliminary calculations relative to the stability and efficiency of the apparatus, and who elaborated many of the designs and made most of the working drawings for its construction. I am particularly indebted also to Mr. E. G. Fischer, chief mechanician of the Survey, whose knowledge of and skill in mechanical appliances were frequently appealed to. Finally it affords me pleasure to state that my friend Mr. E. S. Wheeler, who has had extensive experience with base apparatus, happened to visit Washington about the time the plans for this apparatus were completed and gave me the benefit of his advice and criticism.

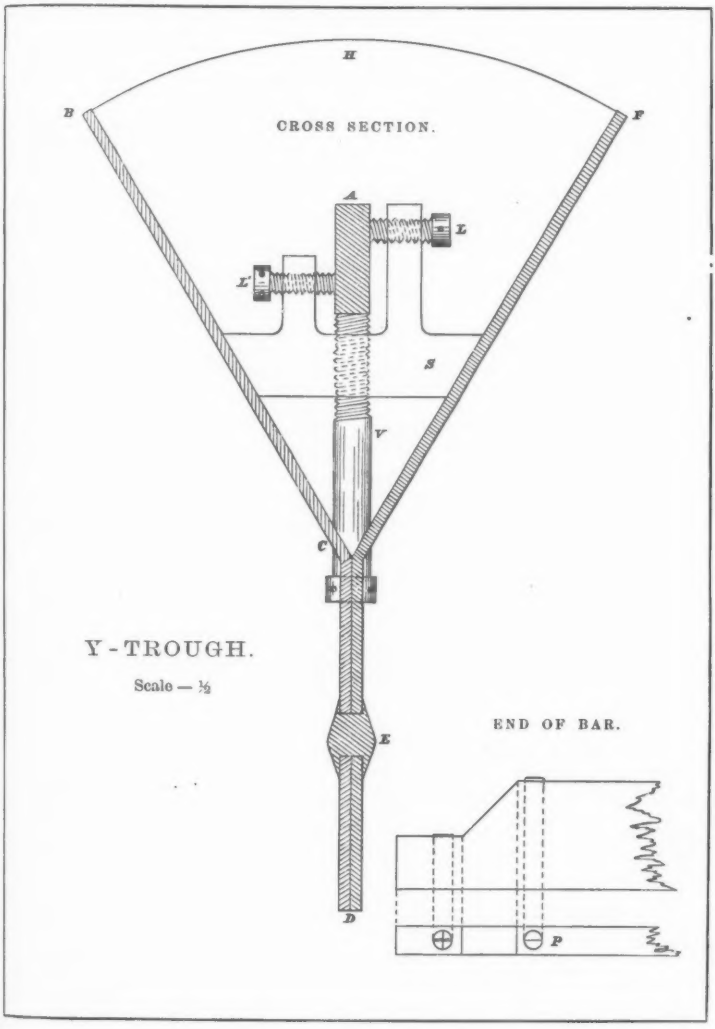
Description of Apparatus.

The measuring bar.—The measuring bar of this apparatus is a rectangular bar of tire steel. It was rolled in the steel works at Lancaster, Pa. It is $5{\cdot}02^{m}$ long, 8^{mm} thick and 32^{mm} deep. A cross-section is shown at A in the accompanying drawing.

The upper half of the bar is cut away for about 2^{cm} at either end to receive the graduation plugs of platinum-iridium, which are inserted so that their upper surfaces lie in the neutral surface of the bar. Three lines are ruled on each of these plugs, two in the direction of and one transverse to the length of the bar. These lines were ruled by Mr. Louis A. Fischer, Adjuster in the Weights and Measures Office. The longitudinal lines, which serve to limit the parts of the transverse lines used, are $0{\cdot}2^{mm}$ apart.

To secure alignment of the bar eleven German silver plugs of 5^{mm} diameter are inserted at intervals of 495^{mm} along the bar so that they project about 1^{mm} above its top surface. The upper surfaces of these plugs are all the same distance, within a few hundredths of a millimeter, from the neutral surface of

the bar On the top of each plug is ruled a fine line in the direction of the bar as shown at P in the drawing. The length of the bar as regards alignment is defined to be the distance between the transverse graduation marks when the upper surfaces of the alignment plugs are all in one plane and



when the lines on these plugs are in one straight line. The means of securing these two adjustments are described below.*

The Y-Trough.—The most important and distinctive part of this apparatus is the trough which supports the bar, keeps it aligned, and carries the ice load essential to control the bar's temperature. This trough is called the Y-trough by reason of the resemblance of its cross-section to the letter Y. The drawing shows a cross-section of this trough. It is made of two steel plates $5{\cdot}14^{m}$ long $25{\cdot}5^{cm}$ wide and 3^{mm} thick. They are bent to the angle B C D of the figure and are riveted together as shown at E, thus making the angle of the trough B C F = 60°. The bar, shown in cross-section at A, is supported at every half meter of its length by saddles, one of which is shown in the figure. These saddles are rigidly attached to the sides of the trough by screws at S, S. Each saddle carries one vertical and two lateral adjusting screws as shown at V, L, L′. These screws serve to fix the alignment of the bar. The lateral adjusting screws of the saddles at the ends of the bar are of the same height, which is equal to that of the lower screw L′ of the diagram. The lateral adjusting screws of the intermediate saddles on either side of the bar are alternately high and low. The object of this disposition is two-fold, to wit: 1st, to prevent pinching the bar, which might more readily occur if the lateral screws were all opposite to one another; 2d, to afford means of rotating the bar slightly about its longitudinal axis, so that for a fixed and nearly vertical position of the trough the graduated surfaces of the bar may be made horizontal. The vertical adjusting screws of the saddles project, as shown in the diagram, below the vertex of the trough, and their capstan heads are accessible through slots cut in the web of the trough. These slots serve also as drainage-ways for the melted ice. To prevent circulation of air through them they are stuffed with cotton batting, through which the water percolates freely. The ends of the trough are closed with wooden V-shaped blocks.

The trough is very rigid in all directions and especially so with respect to vertical stresses. It weighs 82 kilograms exclusive of the bar and ice load. The whole trough is covered by a closely fitting jacket of heavy white cotton felt, which protects the trough and ice load alike from direct radiation.

* The form of bar described is evidently not the best form. Theory and experience indicate that a bar having a Y-shaped cross section with metric subdivisions on its neutral surface would best meet the requirements However, the question which presented itself in planning the apparatus was not what is the best form of bar, but what is the most economical form possessing the requisite properties.

For measuring grade angles a sector reading by two opposite verniers to 10″ is attached to one side of the trough near its middle point. Thus arranged this sector has great stability.

The ice load and ice crusher.—When the apparatus is in use the Y-trough is completely filled with pulverized ice, the upper surface of which is rounded to about the height shown by the curve B H F in the diagram. The amount of ice required for this purpose is about 40 kilograms, or 8 kilograms per meter of the bar's length. The ice, by reason of its weight and the sloping sides of the trough, is kept in close contact with the bar. This is especially the case when the apparatus is in use, for it is then trundled along on its cars with sufficient jarring to overcome any tendency of the ice to pack. For covering the ends of the bar a small quantity of ice is cut with a jack plane. Ice thus cut, like wet snow, packs well and permits making a small conical hole through it to the graduation plugs.

A very essential auxiliary to the use of the apparatus is an ice crusher to pulverize the ice. The machine used is a modification of the Creasey ice breaker manufactured at Philadelphia, Pa. It is a small light hand machine which, as modified, does its work very satisfactorily. With it 40 kilograms of ice may be pulverized in ten minutes or less. The particles of crushed ice vary in size from the smallest visible up to the bulk of a cubic centimeter; and this gradation in size appears to be advantageous as compared with uniformly finer particles like those of snow, since there is less liability of regelation and packing.

The cars and portable track.—The Y-trough is mounted on two cars, the saddles or bolsters of which are attached to the trough 40^{cm} from either end. Each saddle is attached rigidly to the trough above and to a jack screw below. The jack screw is attached to a slide rest which is connected rigidly with the base of the car. The slide rests are provided with screws to give slow motions in the direction of the trough's length and transverse to its length.

The jack screw cylinders have right and left handed threads at their respective ends and are turned by a short capstan bar. They give thus the rapid vertical motion to the trough essential in bringing the bar quickly to focus under the microscopes which define its position.

The cars have each three wheels and run on a portable track whose width is 30^{cm}. Three sections of this track, each 5^{m} long, are provided; and each section is carried forward as the cars are rolled along during the measurement of a line. It thus appears that instead of lifting up and carrying forward

the measuring bar as with most forms of apparatus, this rather delicate and difficult operation is supplanted by that of moving the portable tracks.

The micrometer microscopes.—To define the successive positions of the bar in measuring a line, micrometer-microscopes are used. Through the courtesy of General Casey, Chief of Engineers, U. S. A., the Survey was enabled to borrow the four microscopes and the cut off cylinder of the Repsold base apparatus* used on the U. S. Lake Survey. These are especially well adapted for use with any line measure apparatus. As designed by the Repsolds and as used on the Lake Survey the microscopes were mounted on iron tripods. These latter having been destroyed by fire while stored at the Engineer depot at Willett's Point, N. Y., it was essential to replace them by some equivalent device. In view of the economic and other features of the special work contemplated with the iced bar apparatus it was decided to mount the microscopes on wooden posts set firmly in the ground. To connect the microscope with the post a cast-iron post cap is provided. It fits like a box cover on the end of the post and is clamped rigidly to it by means of a screw.

The microscopes are provided with levels and leveling screws so that their axes may be made vertical. They are mounted on slide rests which give a motion of 2^{cm} in the direction of the line measured or transverse to it. To secure additional displacement in the direction of the line a small rotary motion is provided for in the connection of the microscope with the post cap. The micrometer heads of the microscopes are divided to read microns directly, one revolution of the screws corresponding to $0{\cdot}1^{mm}$. When used in the field the microscopes are shaded from the sun by large umbrellas.

With this method of mounting the microscopes it is advantageous if not essential to set the microscope posts and those supporting the portable track before beginning measurement.

End marks and method of reference thereto.—The method of marking the end of a line is essentially that of the Repsolds and fully described in the Lake Survey Report referred to above. It consists in the use of a metallic bolt terminating in a spherical head, the bolt being embedded in a stone or other stable mass set in the ground. The center of the bolt head is the fiducial point. To refer to this point a cylinder called a cut-off cylinder is used. It terminates at one end with a conical hole which fits over the spherical head. The other end is provided with a transverse level and graduated scale. The scale is

* Fully described in General Comstock's report referred to on page 33.

brought by a rack and pinion motion to focus under the microscope whose position relative to the fiducial point is sought. The scale and level, which are parallel to each other, are placed parallel to the line measured. With the cylinder thus disposed readings of the micrometer on the scale and of the position of the level bubble are made. The cylinder is then turned 180° in azimuth and the scale and level readings are again observed. From these observations and the height of the scale above the bolt head, the horizontal distance (in the direction of the line) between the micrometer zero and the fiducial point may be accurately determined.

Adjustments of apparatus.—The most important adjustment of the apparatus is the alignment of the bar in the Y-trough. This adjustment is made when the ice load is in the trough and after the latter has had time to assume a stable shape. This time does not exceed 15 minutes.

As already stated, the alignment of the bar requires that the upper surfaces of the alignment plugs be in one plane and that the lines on these plugs be in the same straight line. The former requisite is secured by a striding level whose feet are 99^{cm} apart, so that they reach from any plug to the second adjacent plug. Beginning at one end of the bar the plugs are numbered 1, 2, 3,—11. By placing the level feet in succession on plugs 1 and 3, 3 and 5, etc., plugs 1, 3, 5,—11 are brought into the same plane by means of the corresponding vertical adjusting screws, the screws under plugs 2, 4,—10 being loosened if need be to secure this end. Having thus adjusted plugs 1, 3, 5,—11, the level is placed on plugs 2 and 4, 4 and 6, etc., and the vertical screws are brought up to contact with the bar but not raised enough to disturb the previous adjustment of 1, 3, 5—11, which are the principal defining plugs in this adjustment.

To place the lines on the plugs in the same straight line a sharp pointed plumb bob suspended from a fine brass wire stretched over the trough was originally used. This device with the aid of the lateral adjusting screws of the saddles permits placing the lines in proper position within $0{\cdot}1^{mm}$ when the trough is fully loaded with ice. Experience with the apparatus, however, showed that the simpler method of stretching the wire, or better still, a fine thread, close over the plugs when the trough is about four-fifths loaded secures equally good results.

It was feared before using the apparatus that the daily temperature range might produce an appreciable effect on the length of the bar through change in curvature of the trough. Hence the accurate method of measuring such change by the striding level was provided. But experience shows that the

change in shape of the trough gives rise to quite insignificant changes in length of the bar. Indeed, the alignment of the bar may be maintained so perfectly that the correction for its curvature will not exceed a few tenths of a micron.

The grade sector of the apparatus is adjusted to zero when the graduated surfaces of the bar are in the same horizontal plane. To secure the latter condition an engineer's level is used; and with appropriate care the difference in height of the ends of the bar can be made zero with a probable error not exceeding $\pm 0{\cdot}1^{mm}$.

The microscopes are provided with fixed levels, which, when once adjusted, enable the operator to make the axes of the microscopes vertical. They are also provided with clamp screws so that they may be rigidly held in proper position.

When posts are used to support the microscopes, as has been the case with this apparatus thus far, they must be set in their proper positions within a centimeter or two. It is easy and convenient, however, to adjust their sides facing the line to be measured with much greater precision. When firmly set, a line parallel to the base may be deliberately ranged out with a theodolite of high magnifying power, and this line may be defined by suitable marks on each post. Then by simply noting the distance of the axis of the bar during measurement from this reference line an accurate correction for deviation of the bar from parallelism with the base may be obtained. This adjustment of the posts though not essential to the use of the apparatus has been followed.

Another convenient adjustment which the use of posts permits is that of making the tops of several or many posts conform to one grade. By this means, since the four microscopes used are closely alike, the grade angles for several or many bar lengths are nearly the same—a condition favorable to precision in determining grade corrections. As an additional precaution in the use of this apparatus the relative heights of the alternate post tops have been determined with an engineer's level.

Method of measurement.—To conduct the measurement of a line with this apparatus eight men are required, to wit: three observers; one recorder; one man to move the microscopes; and three men to move the car tracks, the microscope shades, and the ice and ice crusher.

The operation of measurement proceeds as follows: The position of the microscope relatively to the fiducial point at the end of the line having been observed as explained above, the rear end of the bar is brought to focus under that microscope by the rear end observer. By means of a lever which grips into the track and hinges on the car, the latter observer

holds the bar near to bisection under the microscope while the front end observer brings his microscope into position over the front end of the bar; to do which he can make use of the lateral motion of the trough, of the microscope, or both. When the bar is adjusted at both ends the rear observer brings the rear end graduation accurately to bisection between the micrometer wires by use of his lever without turning the micrometer screw. Simultaneously he gives the signal "read" to the front observer, who brings his micrometer wires to bisect the front end graduation mark by moving the microscope, the micrometer wires, or both. The observers then read their micrometers and the recorder notes them down in his book, after which the rear observer turns his micrometer screw a half revolution or less backwards. The observers then exchange positions. The rear observer carrying with him his lever applies it to the front car and brings the front end graduation to bisection without disturbing the micrometer threads from their previous position; while at the signal "read" the front observer bisects the rear end graduation by moving the threads with the micrometer screw. They then announce the readings as before and the recorder jots them down, notifying the observers at the time if the screw revolutions differ from their previous values. This process eliminates the relative personal equation of the observers, and checks any blunders of whole revolutions in reading the microscopes, each of them being read four times, and the four readings being the same within a few microns. The probable error of a bisection is less than $\pm 1^{\mu}$.

While the bar is in position under the microscopes, the third observer measures the distance of the front end (and the rear end at starting) of the axis of the bar from the reference line, and adjusts the sector level bubble to center, taking care at the same time to keep away from the microscope posts when the bar is observed. The grade sector reading is then made and recorded, and the bar is rolled rapidly forward to a new position.

As soon as the rear end of the bar is brought safely to position under a microscope the one previously at the rear end is taken up and carried forward by the microscope porter who clamps and adjusts it on a new post. Likewise, as soon as a section of track is passed over it is carried forward to a new position.

The observers stand on platforms which rest at their ends on the ground at a distance of about one meter on either side of a microscope post.

At intervals of 20 to 40 minutes fresh ice is supplied, the trough being run to the rear of or ahead of the two micro-

scopes which were last used. The trough is completely uncovered in this operation and the ice stirred up and supplemented by the amount requisite to replace the waste. This amount is usually 3 to 5 kilograms.

The speed of measurement has varied somewhat with circumstances. It has usually been about 100^m per hour. 750^m were measured in 7 hours on two different dates; and a kilometer would not be an excessive day's work.

The Efficiency of the Apparatus.

Plan of operations with apparatus in 1891.—The plan submitted by me to the Superintendent of the Survey for the use of this apparatus on the Holton Base, of the transcontinental triangulation in Indiana, contained the following recommendations which were approved and carried out during the summer of 1891: (*a*) To construct a 100-meter comparator near the Holton Base; to standardize this comparator by repeated measurements with the iced bar; and to use this comparator in turn to standardize and study the behavior of 100^m tapes or those of less length, or any other form of base apparatus. (*b*) To use the iced bar in addition to make several measures of a kilometer at least of the base line; so that the efficiency of the different forms of apparatus used in measuring the whole base could be tested on the actual ground over which they were applied.

The plan also contemplated making a determination of the length of the steel bar of the apparatus in terms of one of the International Prototype Meters. This was done, but owing to the small amount of time available before going to the field it was impossible to reach anything better than a tentative value.

Before giving the results of the measures made with the iced bar it is proper to give a brief description of the long comparator and of the kilometer whereon the apparatus was used.

The 100-meter comparator.—The 100-meter comparator of the Holton Base was a line 100^m long fitted for measurement with the iced bar apparatus. Twenty-one beech wood microscope posts $1{\cdot}8^m$ long and $15^{cm} \times 15^{cm}$ in cross section were set firmly in the ground 5^m apart on a level plat near the north end of the Base. Alongside of the posts a stationary railway track was laid, the support posts of which were half way between the microscope posts. The ends of the line were marked by brass, spherical headed bolts cemented into the upper ends of stone posts, which latter were well set in beds of concrete. The comparator was covered by a shed 110^m long by 3^m wide. Its length extended nearly east and west. It was covered at the ends and on the south side as well as

overhead, but the north side was left open in order to permit free access of daylight and air.

This comparator was built by Assistant A. T. Mosman after plans drawn up by Mr. Siebert. It answered its purpose very satisfactorily. An efficient auxiliary applied by Assistant Mosman was a sawdust covering to the ground along the comparator. This covering absorbed dust and moisture, and prevented the transmission of disturbances through the ground to the microscope posts. The stability of these posts may be inferred from the measures of the comparator interval given below.

The standard kilometer.—A nearly level portion one kilometer in length of the Holton Base was selected by Assistant Mosman for measurement with the iced bar apparatus. The base line, whose entire length is 5·5 kilometers, runs in a nearly north and south direction across the Crawfish Flats of southern Indiana. The portion selected for the iced bar measures passes for 600^{m} of its length through a dense forest growth, leaving about 200^{m} at either end in open fields. The whole kilometer is on low ground and the part within the forest is, in a wet season, subject to partial inundation. The soil along the kilometer is a stiff clay which is very firm when dry but which assumes a jelly-like mobility and elasticity when saturated with water.

The way through the forest was cleared and the end stones of the kilometer were set under the direction of Assistant Mosman during May and June, 1891. During the latter half of the following August and early September the microscope and track posts were set along the line. Owing to frequent and heavy rains this was a tedious operation. Many of the posts were set in the water which filled the post holes as fast as they were dug. It is impossible, therefore, to present any statistics as to the speed with which this work can be done under usually favorable circumstances. It may be remarked, however, that it is a work which requires but little skilled labor. In addition, it should be said that the microscope posts were set with considerable precision. Accurate spacing of the posts to 5^{m} apart was secured by means of 100^{m} and shorter steel tapes; while the posts were aligned by means of a theodolite. The probable error in position of a post face with respect to the kilometer line does not, I think, exceed $\pm 3^{mm}$; while the probable error of the reference line fixed on the posts as explained above does not exceed $\pm 1^{mm}$.

The bolts marking the termini of the kilometer were cemented in the end stones by Assistant Mosman early in August, after their proper relative positions had been determined by Assistant O. H. Tittmann with the Survey secondary

apparatus.* Intermediate stones dividing the kilometer into four nearly equal sections were set on September 7, 1891. Each of them consisted of a half cubic meter of concrete set in the ground so that its upper surface was about even with the ground surface. On the top of each stone was cemented one of the Repsold cut-off plates which are provided with spherical headed bolts for use with the cut-off cylinder previously described.

When these intermediate stones were set, the ground along the line was so wet that it was a matter of difficulty to keep the water out of the excavations while the concrete was being rammed into place. These stones did not become dry and hard until deep trenches were dug about them on September 18, 1891. For this reason it is probable that these stones were much less stable during the first two measures of the kilometer (Sept. 10–15) than during the last two measures (Sept. 26–30).

Results of measures of 100^m comparator interval.—The earliest experience with the iced bar apparatus showed that the personal equation of the observers may cause appreciable constant error, and hence the method of interchange of the observers already explained was adopted. The first five measures of the comparator interval, however, were made without interchange of the observers. In place of such interchange direct observations for relative personal equation were made on the bar.

The greater part of the measures of the comparator interval were made by starting at the west end and moving the bar toward the east. Some of the later measures were made in the opposite direction and they disclose, apparently, a systematic error depending on the direction of measure. The same kind of systematic error is indicated also by the measures of the kilometer referred to below.

In order to explain the data of the comparator measures clearly and fully let

D = distance between spheres of comparator
= $100^m + 39{\cdot}5^{mm}$ approximately,
B_{17} = length of 5^m steel bar No. 17 in ice,
x = the relative personal equation of the two observers on the bar,
Q = quantity measured on cut-off scale,
v = the most probable correction to Q.†

Then, for one position of the observers a measure of the comparator interval gives an observation equation of the form

* This is an end measure apparatus consisting of two steel rods encased in wood, with mercurial thermometers to give their temperatures.

† The quantity Q involves the error of measuring the line as well as the errors in position of the first and last microscope with respect to the fiducial points.

$$D + 20x - 20B_{17} - Q = v,$$

while for the reverse position the equation is

$$D - 20x - 20B_{17} - Q = v.$$

The following table gives the data furnished by the first group of measures of the comparator. These data include the observations for personal equation, which give rise to observation equations involving the quantity x only. Although the latter equations should have somewhat greater weight than the others they are all treated as of equal weight in this purely preliminary statement.

Data for length of 100m comparator.

Date 1891.	Direction of Measure.	Observation Equations.	mm
July 30	W to E	$D + 20x - 20B_{17} - 39{\cdot}532 =$	$+0{\cdot}052$
30	W to E	$D + 20x - 20B_{17} - 39{\cdot}574 =$	$+ \cdot 010$
30	W to E	$D + 20x - 20B_{17} - 39{\cdot}660 =$	$- \cdot 076$
30	....	$+ 20x \ldots\ldots - 0{\cdot}049 =$	$+ \cdot 013$
31	W to E	$D + 20x - 20B_{17} - 39{\cdot}548 =$	$+ \cdot 036$
31	....	$+ 10x \ldots\ldots - 0{\cdot}040 =$	$- \cdot 008$
Aug. 3	W to E	$D + 20x - 20B_{17} - 39{\cdot}643 =$	$- \cdot 059$
3	....	$+ 10x \ldots\ldots - 0{\cdot}061 =$	$- \cdot 029$
4	W to E	$D + 20x - 20B_{17} - 39{\cdot}624 =$	$- \cdot 040$
4	W to E	$D - 20x - 20B_{17} - 39{\cdot}476 =$	$- \cdot 016$
4	....	$+ 20x \ldots\ldots - 0{\cdot}022 =$	$+ \cdot 040$
7	W to E	$D + 20x - 20B_{17} - 39{\cdot}528 =$	$+ \cdot 056$
7	W to E	$D - 20x - 20B_{17} - 39{\cdot}424 =$	$+ \cdot 036$

The resulting normal equations are:

$$\begin{aligned} 9D + 100x &= 9(20B_{17} + 39^{mm}) + 5{\cdot}009^{mm}, \\ 100 + 4600 &= 100(20B_{17} + 39^{mm}) + 66{\cdot}610; \end{aligned}$$

whence

$$\begin{aligned} D &= 20B_{17} + 39{\cdot}522^{mm} \pm 0{\cdot}011^{mm}, \\ x &= +3^{\mu}{\cdot}1 \pm 0^{\mu}{\cdot}5. \end{aligned}$$

The probable error of an observed quantity of weight 1, or of a single measure of the comparator without interchange of observers to eliminate personal equation, is $\pm 30^{\mu}$.

Later in the season (Sept. 24 to Oct. 6) a second set of measures of the comparator interval was made. In each of these measures the observers interchanged positions, and on two dates the interval was measured in the direction east to west as well as in the direction west to east. The results of these measures are given in the following table which is arranged in the same form as the preceding table.

Data for length of 100m comparator.

Date 1891.	Direction of measure.	Observation equations.	
		mm	mm
Sept. 24	W to E	$D+20x-20B_{17}-39{\cdot}272=$	$+0{\cdot}134$
24	W to E	$D-20x-20B_{17}-39{\cdot}191=$	$+\ {\cdot}149$
Oct. 2	W to E	$D+20x-20B_{17}-39{\cdot}394=$	$+\ {\cdot}012$
2	W to E	$D-20x-20B_{17}-39{\cdot}320=$	$+\ {\cdot}020$
2	E to W	$D+20x-20B_{17}-39{\cdot}432=$	$-\ {\cdot}026$
2	E to W	$D-20x-20B_{17}-39{\cdot}369=$	$-\ {\cdot}029$
6	W to E	$D+20x-20B_{17}-39{\cdot}422=$	$-\ {\cdot}016$
6	W to E	$D-20x-20B_{17}-39{\cdot}370=$	$-\ {\cdot}030$
6	E to W	$D+20x-20B_{17}-39{\cdot}512=$	$-\ {\cdot}106$
6	E to W	$D-20x-20B_{17}-39{\cdot}449=$	$-\ {\cdot}109$

The normal equations from this group are:

$$\begin{aligned} 10D+\ \ 0x &= 10(20B_{17}+39^{mm})+3{\cdot}731^{mm}, \\ 0\ +4000\ &= \qquad\qquad +6\,660; \end{aligned}$$

whence

$$\begin{aligned} D &= 20B_{17}+39^{mm}\,373\pm0{\cdot}019^{mm}, \\ x &= \quad 1^{\mu}{\cdot}7\pm1^{\mu}{\cdot}0. \end{aligned}$$

The probable error of an observed quantity of weight 1, or the probable error of one measure without interchange of observers, is $\pm61^{\mu}$.

The values of D resulting as above from the two groups of determinations differ by $0{\cdot}149^{mm}$, a quantity which is about ten times the average of the probable errors of the separate values. It seems most probable, in view of our experience on the standard kilometer, that this difference is due to a movement of the end marking stones of the comparator. The residuals of the second group of measures indicate a progressive change of this sort.

The data of Oct. 2 and 6 indicate that measures made in the direction west to east give smaller lengths than measures in the opposite direction. Thus the lengths for Oct. 2 are:—

$$\begin{aligned} &\text{Direction W to E} \quad 20B_{17}+39{\cdot}357^{mm}, \\ &\text{“ \quad E to W} \quad 20B_{17}+39{\cdot}400, \end{aligned}$$

Their difference is 43^{μ} and the corresponding difference for Oct. 7 is 84^{μ}. They show an average difference of 64^{μ}, which is equivalent to an error of $1^{\mu}{\cdot}6$ per bar length relatively to the mean of a forward and backward measure of a line.

Results of measures of standard kilometer.—In the measures of the kilometer the observers always interchanged positions in reading on the bar. The results may then be regarded as free from personal equation except so far as such equation

may differ for the two ends of the bar. Each section of the kilometer was measured in both directions. The bar was kept in the same position, relatively to the Y-trough, it had when used on the comparator. A measure from west to east on the comparator corresponds then to a measure from north to south on the kilometer.

Two series of measures of the kilometer were made; one immediately after the intermediate section stones were set and while the ground was very unstable, and one after the ground was dry and very stable. In addition to errors arising from unstable ground the first measures were subject to some errors arising from delay and temporary stops, which were avoided in the second measures. Accordingly, the first series of measures must be regarded as much less precise than the second.

The following table gives the results of these two series of measures. The numerical quantities given are the excesses measured with the cut-off scale over a round number of bar lengths, the number of bar lengths being fifty for each section and two hundred for the whole kilometer. The first measures were made on Sept. 10 to 15 and the second on Sept. 26 to 30.

Results of measures of kilometer.

1st series, Sept. 10 to 15, 1891.

No. of measures.	Direction of measure.	Section 0^m to 250^m.	Section 250^m to 500^m.	Section 500^m to 750^m.	Section 750^m to 1000^m.	$0^m - 1000^m$.
		mm	mm	mm	mm	mm
1	N to S	+6·35	−5·43	+19·08	−20·56	−0 56
2	S to N	+6·52	−4·55	+19·37	−19·28	+2·06
1–2		−0·17	−0·88	− 0·29	— 1·28	−2·62

2d series, Sept. 26 to 30, 1891.

3	N to S	+6·97	−5·50	+19·67	−21·28	−0·14
4	S to N	+7·07	−5·60	+19·76	−21·19	+0·04
3–4		−0·10	+0·10	− 0·09	− 0·09	−0·18

Without attempting to discuss these results here, it may be pointed out that they indicate systematic differences depending on the direction of measurement. These differences agree in sign with those developed in the forward and backward measures of the 100^m comparator as explained above. It may be remarked also that the largest differences in the first series are found in the measures of the second and fourth sections where the ground was least stable.

From the differences (1–2) and (3–4) of the table it appears that the probable error of one measure of a kilometer is $\pm 0{\cdot}76^{mm}$ from the first series and $\pm 0{\cdot}09^{mm}$ from the second series. The second of these probable errors, it may be remarked, agrees well with the corresponding value deduced from the measures on the 100^{m} comparator, to wit, using the average value for the probable error of one measure of the comparator interval:

$$\pm \tfrac{1}{2}\frac{(30^{\mu}+61^{\mu})}{\sqrt{2}}\sqrt{10} = \pm 0{\cdot}10^{mm}$$

It will be of interest in this connection to compare these probable errors of measurement with those obtained with other micrometer microscope apparatus. The apparatus most nearly comparable in this respect with the iced bar apparatus are the Repsold bimetallic (zinc and steel) of the U. S. Lake Survey and the Brunner bimetallic (copper and platinum) used recently by French geodesists. The best work with the Repsold apparatus, on the Olney base 1879, shows a probable error of $\pm 0{\cdot}40^{mm}$ for one measure of a kilometer.* The work of the French on the Paris and Perpignan bases, 1890, 1891, shows $\pm 0{\cdot}67^{mm}$ for one measure of a kilometer.† These larger values are due probably to imperfect temperature indications of the bimetallic apparatus rather than to any material differences of manipulation.

An idea of the stability of the end and section marks of the kilometer may be gained from the above table by computing the differences between the mean lengths of the several sections resulting from the first pair and second pair of measures. Thus we have:

Mean of first pair *minus* mean of second pair of measures.

Section				
Section	0^{m}	to	250^{m}	$-0{\cdot}58^{mm}$
"	250	"	500	$+0{\cdot}56$
"	500	"	750	$-0{\cdot}50$
"	750	"	1000	$+1{\cdot}32$

These figures indicate considerable movements of the marking stones; and it seems not improbable that movements of such magnitude did actually occur, since the stones rose to the surface of the ground and the moisture in the ground varied from the extreme of saturation to the extreme of dryness during the interval which elapsed between the two sets of measures.

* Professional Papers Corps Engineers U. S. A., No. 24, p. 303.

† Comptes-Rendus des séances de L'Association Géodésique International du 8 au 17 Octobre, 1891, p. 182.

Length of measuring bar.—The most important and difficult operation attending the use of the iced bar apparatus is that of deriving the bar's length in terms of one of the International Prototype Meters. As already stated, a preliminary determination of this length was made in July, 1891, just previous to shipping the apparatus to Holton Base, Indiana. The method adopted in this and in most subsequent determinations may be briefly described as follows: Six micrometer microscopes were mounted in a straight line at intervals of one meter. The 5^m distance between the two extreme microscopes was measured with Prototype Meter, No. 21, and this distance transferred from the extreme microscopes to the 5^m steel bar No. 17. All comparisons of this kind were made with both the meter and 5^m bars in melting ice. The 5^m bar was mounted in its Y-trough and the meter bar in a wooden box. 40 to 45 kilograms of ice were used for the 5^m bar and 10 to 12 kilograms for the meter.

Assuming constancy of temperature of the bars under comparison the precision of the method just outlined evidently depends on the stability of the microscopes used. The first series of comparisons of July, 1891, and several series of February to May, 1892, were made on the office comparator. This comparator was not designed to meet the special requirements of the case and it did not meet them satisfactorily. The microscopes were too unstable. Their instability was due primarily to the manner of mounting them. They were each suspended by a cast iron bracket from a wrought iron I-beam about 6^m long which is supported at its ends on brick piers. The focal planes of the microscopes fell about $0{\cdot}5^m$ below the beam. The beam was wrapped with cotton batting and covered with a wooden casing to prevent rapid temperature changes. Resting as the beam does by friction on the piers, it is in general in a state of longitudinal stress, which is frequently relieved by vibrations communicated to the piers by vehicles passing in the adjacent street. Changes in this stress produce changes in the curvature of the beam and entail exaggerated motions in the microscopes. The temperature of the comparing room (which is underground) changes very slowly from day to day when not occupied long by observers or when lighted for short periods. The comparisons in question, however, required occupying the room for some hours per day, and the heat from the observers and the electric lights caused notable changes in the temperature of the beam as well as of the air in the room. These changes no doubt caused more or less irregular displacements of the microscopes.

The observations were so arranged as to eliminate the effects of uniform motions of the microscopes. Thus in the first series of determinations the following program was adhered to:

1. Measure of distance between end microscopes with meter,
2. " " " " " with 5^m bar.,
3. " " " " " " meter;

the second measure with the meter being made in a direction opposite to that of the first. In later measures on this comparator the above program was supplemented by an initial and final measure with the 5^m bar.

The observations were made by two persons observing simultaneously at the respective ends of either bar. The observers also exchanged positions in all cases to eliminate personal equation.

The determinations made in the manner just described showed large ranges, amounting to 1/200000th part at the maximum; and with the hope of overcoming the effects of the irregular motions of the microscopes a different method was tried with the same comparator. The essential feature of this method consists in the use of an intermediary 5^m steel bar subdivided into meter spaces. This bar, known as No. 18, is similar in form to No. 17, except that it is cut down to the mid depth at four intermediate places as well as at its ends. The lines subdividing the bar into meter spaces are ruled on platinum iridium plugs. This bar was mounted in the steel Y-trough where its flexure could be controlled in the same way as that of bar No. 17. The sub-spaces of No. 18 when packed in melting ice were determined by direct comparisons with Prototype Meter No. 21. Three series of six measures each of the sub-spaces, and hence of the whole length of the bar, were made. In the intervals between the first and second and the second and third series, bars 17 and 18 were compared. For this purpose No. 17 was mounted in an auxiliary wooden trough similar to the Y-trough. Notwithstanding the diminished time-interval during which dependence on the stability of the microscopes was required by this process, the results attained were still too erratic to give confidence. The range in values for the metric sub-spaces of No. 18 rose to 1/200000th part and in the values for the whole length, or sum of these spaces, to 1/300000th part; and these ranges appeared to be directly referable to the large progressive, and frequently large sudden, movements of the microscopes.

Such being the unsatisfactory quality of the results attained on the office comparator, it was determined in June, 1892, to build a new comparator designed more especially to meet the

requirements of the iced bar apparatus. This comparator was constructed in a lot adjacent to the Survey Office. Briefly described it consists of six brick piers resting at intervals of a meter on a foundation of six cubic meters of well rammed concrete. The foundation and the piers are set in Portland cement and weigh about twelve tons. The foundation, which rises to near the ground surface, is covered to the depth of a decimeter with sawdust. Each pier carries a micrometer microscope. The latter and their connections with the piers are wrapped heavily with cotton batting. The meter and 5^m bars were moved under the microscopes on portable tracks supported on posts isolated from the piers. The track for the 5^m bar was that used in the field, and the mode of handling this bar was precisely the same in all respects as that followed in measuring a line.

The microscopes as mounted on this comparator proved to be very stable notwithstanding the fact that they were subject to the daily range in air temperature except so far as they were protected by cotton batting wrappings. The effect of the observers' presence near the comparator was undoubtedly less than in the office comparing room, and the use of artificial light was avoided entirely.

The program followed in the use of the new comparator comprised three measures of the distance between the end microscopes with the meter and two measures with the 5^m bar in each set of observations. The measures with the meter were made in opposite directions alternately along the comparator. Twenty sets of observations were made with the 5^m bar in each of its two orientations relatively to the Y-trough and microscopes. The consistency of the results attained leaves little to be desired. The probable error of a single determination of the length of the 5^m bar in terms of the Prototype is $\pm 1^{\mu}{\cdot}8$ from one group of measures and $\pm 1^{\mu}{\cdot}7$ from the other. The range in the one case is $12^{\mu}{\cdot}3$ and in the other $8^{\mu}{\cdot}5$.

The following table gives an abstract of the results obtained in the manner described above for the length of the 5^m bar. The values given are subject to corrections for flexure of the 5^m bar, which, however, cannot exceed a few tenths of a micron. The probable errors are those which come from the discrepancies between the individual and mean results of a group of determinations. Each result is derived from an equal number of measures with the meter and 5^m bars in their two different orientations. The first, second, and third results were obtained from the Office comparator, the third one depending on the method wherein the auxiliary bar, No. 18, was used. The fourth result was obtained from the new comparator.

Summary of results for length of B_{17}.

Date.	No. of Measures.	Mean length of bar.
July, 1891	10	$5^m - 11^\mu \cdot 0 \pm 1^\mu \cdot 4$
Feb. and March, 1892	20	$5 - 15 \cdot 2 \pm 0 \cdot 6$
April and May, 1892	18	$5 - 11 \cdot 7 \pm 1 \cdot 6$
July and August, 1892	20	$5 - 16 \cdot 8 \pm 0 \cdot 3$

Without desiring to discuss these data here, it may be said that so far as is known at present the probable errors are fairly trustworthy indices of the precision of the several results. The range among them is but little in excess of the millionth part of the bar's length, and is no greater than the probable errors would lead one to expect.

It may be stated also that the external air temperature varied for the different groups of comparison from 5° to 40° C. The average air temperatures for the two most important groups, namely, those of February and March, 1892, and July and August, 1892, were about 5° C. and 35° C. respectively. Hence it does not appear that the bars in ice were affected appreciably by the external air temperature. Finally, it should be said that a systematic difference in the length of the bar, according as the one or the other of its ends is to the right in the Y-trough, is indicated by each group of comparisons. This difference appears to be an inequality of relative personal equation of the observers at the two ends of the bar, and may be due to the considerable inequality in widths of the terminal graduation lines.

Concluding remarks.—The question may be asked, does the bar take the temperature of melting ice when fully packed in it? I am unable to give a decisive answer to this question at present, but there appears to be no reason to suppose that it takes a materially different temperature. Repeated observations on mercurial thermometers placed in the ice alongside the bar show that they read zero within the unavoidable errors of a few hundredths of a degree. That the bar assumes a fixed length within very narrow limits is, it would seem, demonstrated by the small range among the measures of the 100^m comparator and the kilometer sections referred to above, and especially by the recent work on the new comparator. This latter work appears to justify the conclusion that the mean of four determinations of the bar's length in terms of the Prototype meter, made in the manner described above, cannot have a greater probable error than one micron. It is evident therefore, in view of the unavoidable errors of observation in such work, and in view of the fact that the bar's expansion is about 55^μ per degree Centigrade, that there is a very small margin for change in the bar's length.

The time required for the bar to acquire a sensibly stable length is less than ten minutes. The rate of temperature-change is so great in the early stages of freezing that ninety per cent or more of the contraction of the bar occurs within a minute after it is well surrounded by ice. The corresponding time required by the Prototype meter to reach a stable length appears to be less than five minutes, which is less than the time essential to properly pack it in ice.

A query may also arise as to whether the bar, resting as it does with considerable friction on the vertical adjusting screws of the Y-trough, may not change length by reason of longitudinal stress communicated by the trough. In answer to this query it may be said that the experiment of putting the trough alternately under tension and compression in quick succession has been tried on several occasions without disclosing any effect on the bar.

With regard to the precision attainable in the measurement of a line with this apparatus, it would appear that the error of operation may be rendered insignificant in the mean of a few measures of a line, so that the probable error of the mean length may be diminished to that of the bar when expressed as a fraction of its length. It appears practicable to determine that length with a probable error not exceeding 1/5000000th part, and this, therefore, would appear to be an attainable precision in the measurement of a line with the apparatus.

Although the use of this or similar apparatus is not to be recommended for primary bases in general, since it gives a needless precision, it will compare favorably I think on the score of economy with any of the earlier forms of apparatus which have given a precision approaching the millionth part of a measured line. The proper function, however, of the iced bar apparatus appears to be that of an intermediary between the lighter and cheaper forms of base apparatus and the standard meter. By means of this bar it appears practicable to standardize long steel tapes so accurately that they will give all needful precision for bases in general at much less cost than other forms of apparatus.*

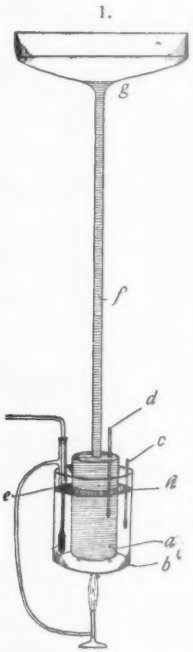
Office Coast and Geodetic Survey, Sept. 15, 1892.

* Experience of the author in the use of 100^{m} steel tapes with mercurial thermometers to give temperature, on the Holton Base, 1891, shows that the length of such a tape can be determined with a probable error not exceeding 1/2000000th part, and that the probable error due to errors of operation and temperature in the mean of n measures of a line k kilometers long need not exceed

$$\pm 2^{mm}\sqrt{\frac{k}{n}}.$$

ART. V.—*Some Experiments with an Artificial Geyser;* by JAMES C. GRAHAM.

As a result of observations during his travels in Iceland in the summer of 1846, Professor Bunsen advanced the explanation* of the eruptions of the Great Geyser which has been almost universally accepted since then. In 1847,† there appeared an article in which Professor Bunsen's views were disputed and it was in answer to this article that Professor Müller published in 1850 the first account of which I can find any record, of experiments with an artificial geyser.‡ Since that date artificial geysers have been often constructed and exhibited, the most complete descriptions in English of such geysers, being found in Professor Tyndall's "Heat as a mode of Motion" (Appleton, 1865, p. 139) and in a description of Müller's experiments in Hayden's Report for 1878 of the U. S. Geological Survey (p. 420).



In all of these experiments, however, the artificial geyser has not been constructed to explain geyser phenomena in general but has been restricted to an imitation of the Great Geyser of Iceland. This geyser is peculiar in having the boiling point reached first, not at the base of the tube or throat, but at a position considerably above this. It is doubtful if this peculiarity has been repeated in any geyser which has been elsewhere studied. In my work, therefore, I have not applied heat at an intermediate point of the tube, but only at the base. The description of my apparatus is as follows:

It consists (fig. 1) of a glass tube, *f*, surmounted by a funnel, *g*, and terminating in an iron cylinder, *a*. This cylinder is immersed (to the line *h*) in a bath of mercury contained in another iron cylinder, *b*; *c* and *d* are thermometers, registering the temperature of the mercury and of the geyser fluid respectively; *e* is a mercury gas-cock, so arranged that an

* Poggendorff, vol. lxxii, p. 159.

† Die Fortschritten der Physik im Jahre, 1847, dargestellt von der physikalischen Gesellschaft zu Berlin, p. 92.

‡ Poggendorff, vol. lxxix, p. 350, 1850.

increase of heat causes an expansion of mercury in the bulb below, thereby decreasing the heat by cutting off the gas. The object of this device is to maintain, as nearly as practicable, a constant temperature in the mercury. The whole is supported upon a frame not shown in the figure.

The important dimensions of the apparatus are:

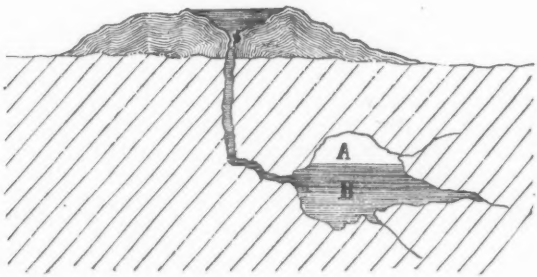
Internal diameter of inner cylinder	$0{\cdot}089^{m}$
" height " "	$0{\cdot}136^{m}$
" diameter of tube	$0{\cdot}021^{m}$
Height of tube	$1{\cdot}44^{m}$
Height to which cone is filled	$0{\cdot}035^{m}$
Total height of fluid column	$1{\cdot}611^{m}$

With this apparatus we are enabled to get not only qualitative but quantitative results to a large extent, for all the factors are nearly constant, and where variable, the amount of variation can be detected.

The object of my experiment was to see if any light could be thrown upon the subject of "soaping geysers" by the study of an artificial one. But before considering this subject, I wish to mention an observation which seems to me to give a criterion, judged by which certain geysers can be proven not to operate upon the McKenzie principle.

It will be recalled that Sir George in explaining the phenomenon of an eruption supposed a tube communicating with a subterranean cavern in the way indicated in the accompanying sketch, fig. 2.

2.



The water is kept in the tube at the level indicated, by the steam pressure in *A*, arising from the heated water *B*. An eruption takes place when the pressure in the cavity becomes great enough to lift the column in the tube sufficiently to cause an overflow and thus to lessen the pressure of the column. By forcing the tube of my artificial geyser part way

down into the iron cylinder, a geyser is formed of practically the same type that Sir George's theory requires. When this is done, this change is at once observable in the eruption. *They are unpreceded by steam bubbles.* It is evident that this must be so; for the peculiar form of the tube and chamber are of no avail in Sir George's theory unless the temperature of the water reaches the boiling point before the water-level in the subterranean chamber has been forced down to the opening of the tube into the cavity. And until this level is reached no steam bubbles of any consequence can escape. The conclusion which I would draw would be that those geyers in which the eruptions are markedly preceded by bubbles cannot be classed as "McKenzie's."

To turn now to the main subject of this paper, that is the effect of soaping geyers.

It has long been thought that by throwing stones or putting soap into a geyser, a premature eruption could be brought on in the cases of geysers erupting periodically, and that in some cases, hot springs, not known to be active, have by this means been caused to throw out the water in their basins in geyser-spouts. It is evident, however, that this matter is not capable of absolute proof; for, as none of the geysers are perfect in regard to the equality of their periods, we can never say positively that the geyser would not have erupted when it did if it had not been soaped. Or, in the case of forced eruptions of hot springs, it might be considered that these springs were geysers with periods so long that the nature of the spring was now for the first time revealed. To be sure that such would be the case in many instances is improbable but not impossible, especially as but comparatively few springs have been successfully experimented upon. If now, in the artificial geyser, it can be shown that with the same conditions as to the amount of fluid, heat, barometric pressure, etc., the periods of eruption are shorter when the soapy fluid is used than when the fluid is simply water, it will then be conclusively proven that the soap does cause a premature eruption. The question of why it so acts, may then be attacked.

There are many difficulties in the way of making these seemingly simple observations.

It is necessary that the amount of fluid in the geyser should be the same in all observations; but owing to splashing and evaporation, this has a constant tendency to vary. The splashing was provided against by filling the geyser not simply to the top of the tube, but part way ($3{\cdot}5^{cm}$) up the funnel as well, which had the effect of deadening the eruption. The error due to evaporation was provided against by adding a determined amount of fluid at the end of each eruption. By

this means the error is made a nearly constant one, and the height of the column is not affected.

The question of a constant supply of heat cannot be entirely solved, or at least could not be with the apparatus at my control. But by the aid of the self-regulating gas-cock I was able to keep the supply nearly constant, and by means of many readings of the thermometer immersed in the mercury bath, a comparison could be made in the cases of different eruptions which I think are sufficiently accurate and definite.

The error of barometric pressure variations was overcome by making observations on various days and comparing those in which the heights of the mercury columns were nearly the same.

There were also many minor factors, such as the temperature of the room in which the observations were made, which had to be taken into account and eliminated when possible.

In making the statement of the results of these experiments, only a few from several hundred observations will be given; those in which the various conditions were most favorable to accurate determinations. In Tables I and III the fluid used was ordinary water from the city reservoir. In Tables II and IV it was a solution of Ivory soap in water, of such strength that it was of a molasses-like consistency when cold, but of course much more fluid when warm.

Temperature of room.	Temp. Hg. at erupt.	Temp. Hg. after erupt.	Temp. aq. at erupt.	Temp. aq. after erupt.	Time of erupt. H. M. S.	Period between erupts.
Water.				I.	Barom. 30·24 in.	
21·5°	107·5°	104·5°	103·2°	94°	11 35–25	6–30
21·5	107·5	104 8	103·2	94	40–25	5–25
21·5	107·2	104·5	103·2	95	46–30	6–05
21 5	107·2	104·5	103·2	95	52–50	6–20
21·5	107·2	104·3	103 2	94	59–15	6–25
Soap and Water.				II.	Barom. 30·2	
22	107 5	104·7	103	91·5	14–	5–15
22·5	107	104·7	103	91·5	19–10	5–10
22·5	107	104·6	103	91·5	24–20	5–10
22·5	107	104·7	103	91·5	24–55	5–35
22	107	104·6	103	91·5	35–10	5–15
22	107	104+	103	91·5	40–20	5–10
Water.				III.	Barom. 29·74	
22	106·5	103·8	103·1	94	10 21–05	7–50
22	106·5	103·5	103	93	29	7–55
22	106·5	103·8	103	94	37–10	8–10
22	106·5	103·8	103	94	44–40	7–30
22	106·5	103·7	103	94	52–35	7–55
22	106·5	?	103	94	0–05	7–30
Soap and Water.				IV.	Barom. 30·8	
21·5	106·5	103·5	103·1	92	9 52–20	6–10
21·5	106·5	103·7	103·1	91	58–15	5–55
21·5	106·5	103·5	103·1	91	10 4–25	6–10
21·5	106·5	103·5	103·1	91	10–15	5–50

In these tables although the conditions are not precisely the same, it is evident that in those cases in which the soap was used, the periods between the eruptions were much shortened. The differences in the temperature of the room and mercury, and the changes in barometric pressure, are so slight as to be unworthy of notice, or in a direction contrary to produce the obtained result. It is also noticeable that the soap solution is cooled much more after each eruption than is the case with pure water. This is due to the fact that as the periods are shorter, convection and other causes, could not operate so completely to heat the water in the geyser throat, and this cooler water in rushing down at the end of the eruption, lowers the general temperature. This factor also acts against the tendency of the soap solutions having shorter periods, as it requires a greater elevation of temperature at each eruption than is required in the case of pure water.

I think that these observations show conclusively that soaping geysers does have a tendency to shorten their periods. The question which now confronts us is: How does it produce this effect? I will confess at once that I have not solved this problem very satisfactorily; but I have at least shown that some theories which have been advanced as to the *modus operandi*, cannot hold.

It is evident that to bring about an eruption, what must be done is to cause the water to boil at some point in the tube; and *any* effect which the soap has upon the boiling of the geyser water may be a factor in the solution of the problem, provided only the effect is in a positive direction. By being in a positive direction, I mean having a tendency to hasten, rather than to retard, the boiling. What these various effects are, I will now proceed to consider.

First, as to the weight of the column. If the specific gravity of the soapy water were much less than that of the water alone this would lessen the pressure and so lower the boiling point for any given depth. By determination, I found that considering the water used of a specific gravity of 1, the specific gravity of the soap solution was 1·00454. The determinations were in both cases at a temperature just below the boiling point and the fluids were those actually used in operating the geyser. The effect of the difference of specific gravities would therefore be negative as regards hastening an eruption.

Second, as to the boiling point itself. In this respect there was no difference, it being 99° C. for both. These observations were made at the same time and with the same thermometer, etc., to avoid all chances of error.

Third, as to the specific heat. If the specific heat of the soap solution were less than that of the water, less heat would be required to bring a given amount to the boiling point, and with a constant supply of heat, less time would be required. This observation it was impossible for me to make with any great accuracy, but from the results of my experiments, I should say that there was no appreciable difference between the two specific heats.

Fourth, as to the retention of heat. In the tables concerning the periods of eruption, it was noticed that the temperature was lowered more after an eruption in the case of the soap and water than in the case of the pure water. As the boiling point was the same in both cases (compare Tables III and IV) it was considered that this was due to the columns above being less heated in one case than in the other. This at once suggests a possible explanation. The heat is retained in the lower part of the tube where it can be utilized in causing the fluid to reach the boiling point, and so not wasted in raising the temperature of the whole column. How, then, is this heat retained, or conversely, how is the heat lost in the case of the water geyser?

Convection is, of course, the principal method by which heat is conveyed from the lower part of the tube to the upper portion. If the viscosity of the fluid retards convection, this then would cause the heat to be retained below. To test this matter, I constructed a piece of apparatus by which a column of water was heated at the base only, and the temperature attained by the water in the upper part of the tube could be read at given intervals of time. By changing the fluid to soap and water, the influence of the viscosity upon convection, at least as far as it affected my problem, could be determined. After a number of experiments with the fluids at high temperatures, I was somewhat surprised to find that the thermometer in the soap solution showed in every case, a slightly greater degree of heat than in the case of the water. That is, viscosity did not seem to retard the escape of heat by convection. Hence convection cannot be the factor sought.

In all eruptions of the geyser the final out-rush of the water is preceded by the rise of bubbles of steam (and of air, possibly, to some extent), through the column of water. If these bubbles are retarded in their ascent by the viscosity of the fluid, they will give out more heat in the lower part of the tube and so carry less to the upper. Accordingly, I devised an apparatus to measure by the chronograph, the time required for the bubbles to pass a given distance through the different liquids against the force of gravity. The average of about twenty five readings in each fluid showed that the time re-

quired was the same in both cases to the hundredth of a second.

From these experiments I am forced to the conclusion of Mr. Arnold Hague, which he states in his paper entitled "Soaping Geysers" read before the New York meeting of the American Institute of Mining Engineers in February, 1889. "Viscosity must tend to the retention of steam within the basin, and, as is the case of superheated waters, where the temperature stands at or above the boiling point, explosive liberation must follow. All alkaline solutions, whether in the laboratory or in nature, exhibit, by reason of this viscosity, a tendency to bump and boil irregularly. Viscosity in these hot springs must also tend to the formation of bubbles and foam when the steam rises to the surface, and this mixture aids to bring about the explosive action, followed by a relief of pressure, and this to hasten the final and more powerful display." The retention of steam referred to in the above quotation is an entirely distinct phenomenon from that of the interference in the rise of steam bubbles investigated in my experiments. It is an interference with the actual formation of the bubbles rather than with the rise of them after formation. That such an interference does actually take place is also shown by the fact that the bubbles liberated in the soap geyser are far less numerous than in the case of the water geyser. Also, when they occur in the case of the soap geyser, they are large and of sudden formation, which would tend to cause an overflow of the basin and thus to relieve the pressure.

In these facts then in regard to the formation of the steam bubbles, I take to lie the main explanation of the phenomenon, believing the surface bubbles to be a much less important factor.

Physical Laboratory of Wesleyan University,
Middletown, Conn., Oct. 12, 1892.

ART. VI.—*Observations of the Andromed Meteors of November 23d and 27th, 1892;* collected by H. A. NEWTON.

ON the evening of Nov. 23d there were seen at various places in the United States shooting stars which radiated from Andromeda, and which were apparently fragments from the Biela Comet.

At New Haven, Conn.—Dr. Elkin was in the open air for some minutes about seven o'clock on the evening of Nov. 23d. The sky was clear and he feels confident that if there had been a great number of shooting stars, he would have certainly seen them. About a quarter past ten o'clock he was informed by Mr. Chase that the meteors were coming in unusual numbers. For a time they came so as to furnish about ten per minute visible by one observer. Only a part of the sky was clear. Most of the trains were short, not exceeding four degrees in length. Very few were as bright as stars of the first magnitude.

Dr. Chase of the Yale Observatory was walking across the Observatory grounds between ten o'clock and a quarter past ten and in seven minutes counted 16 meteors. In the twenty minutes following he saw enough more to make in all more than 100 flights, that is, in 20 minutes he saw more than 84 meteors. Most of them were faint and had short tracks. Very few left trails. One however left a trail that was visible during 15 seconds. The radiant was very close to Gamma Andromedæ. About $10^h\ 35^m$ he and Dr. Elkin gave up counting, as the sky was nearly overcast and therefore the counts were unsatisfactory.

Mr. Van Name, the University Librarian, counted 50 in five minutes between $10^h\ 50^m$ and $10^h\ 55^m$. He was looking southeast. The direction was almost straight down. There were no very bright ones, though the train of one lasted a second.

Observations of Meteors at 1905 N St., Washington, D. C.—Prof. J. R. Eastman writes: While crossing the street at the corner of N and 19th sts., I saw a meteor near α Cassiopeæ, quickly followed by two more. In a short time I counted 15 and from $10^h\ 24^m$ to $10^h\ 43^m$ I counted 102 meteors. From $10^h\ 59^m$ to $11^h\ 11^m$, 111 were counted, and from $11^h\ 19^m$ to $11^h\ 41^m$ I counted 114, or, in all, 327 meteors in 53 minutes by one observer. They were scattered all over the sky wherever I could see, but in a general way they seemed to diverge from a point about half way between γ Andromedæ and γ Cassiopeæ and near φ Persei. The coördinates of this radiant

would be about $1^h\ 35^m$ and $+51°$. Owing to the wide dispersion of the bodies the location of the radiant was very difficult and, at best, could be only approximate. Several meteors were quite bright, and one left a bright train showing brilliant red and green tints. The behavior of several meteors gave the impression that they were not more than 100 yards from the observer; I observed this peculiarity in several instances in the shower of Nov. 27, 1872.

Prof. Eastman also communicates the following notes by Mr. D. Horigan, watchman at the new Naval Observatory:

Some meteors appeared soon after dark. At 7^h were quite numerous. At 8^h, increasing in number. At 9^h, still increasing, several seen at once. $9^h\ 30^m$, still increasing, some leaving trains of red and orange tints. $9^h\ 40^m$, too numerous to count. Radiant apparently east of "chair of Cassiopeæ." $10^h\ 0^m$ to $10^h\ 45^m$ still increasing. Began to decrease somewhat after $11^h\ 25^m$. About $11^h\ 25^m$ quite a cluster fell from about 15° below Polaris to the horizon.

At midnight many visible but apparently growing fainter. $0^h\ 20^m$, reduced to counting scale but rather late to begin now. $1^h\ 0^m$, many still falling, but number decreasing. $3^h\ 0^m$, some to be seen yet. After $3^h\ 0^m$ A M. on the 24th made several observations and found more or less falling till daylight.

At Griswold, Conn.—Prof. A. W. Phillips was on the evening of Nov. 23d riding in an open carriage in Griswold. Between $8^h\ 15^m$ and $8^h\ 50^m$ he counted nearly 200 shooting stars. Most of them were faint and had short paths; a few were brilliant. The radiant was in Andromeda, but was not accurately located by him in the constellation. At times they came in rapid succession, then frequently a lull. After reaching home ($8^h\ 50^m$) he saw through a window that the display continued. About $9^h\ 10^m$ it became cloudy, and after that more were seen by him.

At Meriden, Conn.—Mr. E. W. Abell reports that he and his two sisters were at ten minutes past eight looking attentively at Jupiter for at least three-quarters of a minute and if there had been an unusual display at that time they would certainly have seen it. At $9^h\ 26^m$ he and his mother went out upon an errand and at once saw the shooting stars "falling quite rapidly, sometimes almost as fast as we could count." A regular watch was shortly afterwards arranged for, four persons watching each a quarter of the heavens, and counting aloud to prevent duplication. In the five minutes between $10^h\ 7^m\ 30^s$ and $10^h\ 12^m\ 30^s$ there were seen to the south 29, to the west 18, to the north 35, and to the east 52 meteors; in all 134. A few minutes later two of the party looking to the

east counted in five minutes (beginning about $10^h\ 20^m$) 71 meteors. Mr. Abell then began to locate the radiant. It was between Aries and Andromeda but the meteors did not fall so numerously as before and it took five or ten minutes to see three or four start near enough to the radiant to locate it approximately,—a little to the north of the triangle,—between Aries and Andromeda. A sketch of the stars made by Mr. Abell places the radiant near R. A. $1^h\ 40^m$ and Dec. $+35°$. The sky was very clear all the time.

At Albuquerque, N. M.—Rev. M. R. Gaines writes that at a little before ten o'clock (presumably by time seven hours from Greenwich) the meteors were quite frequent, — he "counted 100 in a few minutes, as many as three at a time being visible." No very large ones, and none with trains of any great durability were noticed. He was told that the shower was noticed two hours earlier than the time when he first saw it. At eleven o'clock the rate was somewhat less than when first noticed, but meteors were still frequent at that hour.

At other places.—From the newspapers we learn that Profs. Young, Rees, Davidson, and Hale, and others observed the display. It seems better to wait for their responsible accounts than to incur the risk of perpetuating the unavoidable errors of newspaper reports.

This display seems to me to be the successor of the sprinkle observed at New Haven and Germantown on the 24th of November, 1872 (this Journal, II, vol. v, p. 53) rather than of the more brilliant display seen in Europe three days later, that is Nov. 27th, 1872.

There were no Andromed meteors seen so far as I know on evenings of the 24th, 25th or 26th, though in New Haven, and generally in the eastern part of the United States the skies were clear. On the night following Nov. 27th it was generally cloudy in the United States.

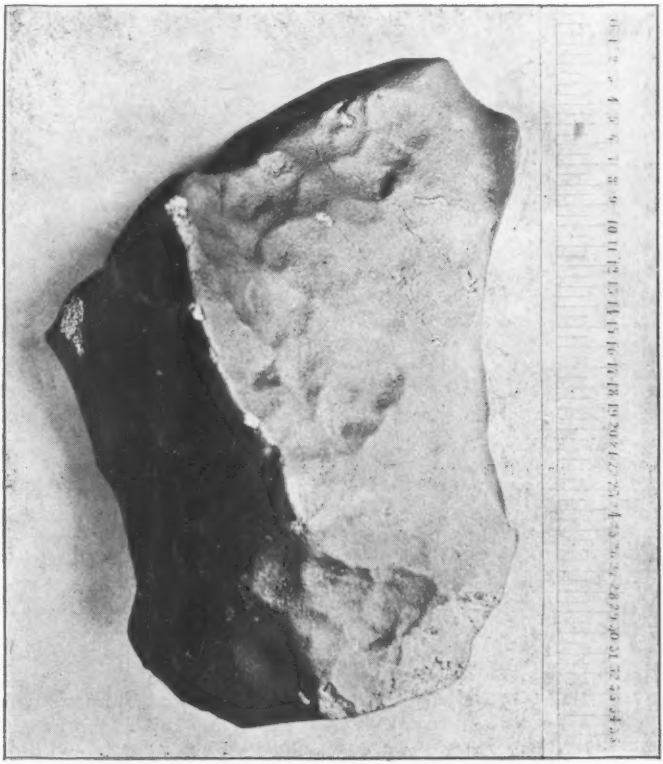
Shooting Stars in Mexico, Nov. 27th.—Mr. A. J. Newton and Mrs. A. G. Dana left Torreon in the afternoon of Nov. 27th en route for New Orleans. Between eight and eleven o'clock they saw through the windows of the car (single thickness of plate glass) a large number of shooting stars. It seemed hopeless, says Mrs. Dana, to count them. They came two and more at a time, and they formed a continual display of celestial fireworks.

ART. VII.—*Preliminary Notice of a Meteoric Stone seen to fall at Bath, South Dakota;* by A. E. FOOTE.* With Plate III.

ON the 29th day of August, 1892, about four o'clock in the afternoon, while Mr. Lawrence Freeman and his son were stacking upon his farm two miles south of Bath, they were alarmed by a series of heavy explosions. On looking up they saw a meteoric stone flying through the air followed by a cloud of smoke. Its course was easily traced to the point where it fell within about twenty rods from where they were standing. The stone penetrated the hardened prairie to a depth of about sixteen inches and when reached it was found to be so warm that gloves had to used in handling it. Three small pieces of an ounce or two each had apparently been blown off by the explosions, but the stone still weighed 46¾ lbs. One of these small pieces was found by some men not far distant and was broken up and distributed among them. The explosions were plainly heard by a large number of people at Bath, two miles away, and at Aberdeen, nine miles away, it sounded like distant cannonading. The exterior of the stone presents the usual smooth black crust. The interior is quite close-grained resembling in texture the stones from Möcs. The iron is abundantly disseminated through the mass, and although the grains are small they are easily distinguished and separated on pulverizing.

Preliminary tests made by Mr. Amos P. Brown of the mineralogical department of the University of Pennsylvania prove the presence of nickel and cobalt in considerable quantity. Plate III shows the form of the stone and the size is indicated by the metric scale at the side. An affidavit signed by Charles Freeman (before H. T. Root, Notary Public) stating the facts of the fall, is in the hands of the writer to whom the stone was sent.

* A verbal communication on the above was made before the Academy of Natural Sciences of Philadelphia (November 23, 1892.)



A Meteoric Stone which fell at Bath, South Dakota, Aug. 29th, 1892.
Weight, 46¾ pounds. Photographed with metric scale.

SCIENTIFIC INTELLIGENCE.

I. Chemistry and Physics.

1. *On the Influence of Foreign substances on the Form, the Size and the Purity of Crystals separating from a solution.*—In continuation of his investigations on isomorphism, Retgers has studied the influence, in a solution from which crystals are separating, of the presence of foreign substances upon the form, the size and the purity of these crystals. It is well known for example that sodium chloride, which crystallizes in cubes from solution in pure water, separates in octahedrons if urea be present. Lead nitrate which separates from an aqueous solution in white porcelain-like crystals, appears in perfectly clear, transparent crystals if nitric acid be added to the solution. Ammonium chloride which is deposited from solution in water in insignificant grains and skeleton-like crystals, separates in crystals a centimeter long if the solution contain some ferric chloride. If a cubo-octahedron of sodium chloride be placed in a concentrated aqueous solution of salt, the author observes that the cubic faces grow faster than the octahedral, and so produce finally a cube; while a similar cubo-octahedron placed in a solution containing urea, becomes finally an octahedron by the more rapid growth of the octahedral faces. The cause of this difference lies evidently in a contact difference in the two cases between the crystal-faces and the liquid; a change in fact in the capillary attraction. Adhesion depends upon the nature of the liquid as well as upon that of the solid, the same liquid acting very differently upon different solids. Moreover the cubic and the octahedral faces of the cubo-octahedron are physically quite different; this difference being often evident in their difference of luster. Sodium chloride gives cubes in pure water, or in water containing ferric chloride or a lead halide; but it yields octahedrons in water containing urea or chromium chloride. The potassium halides give cubes in all these cases, except where the solution contains a lead halide, when the crystals are octahedrons. Potassium chloride however, which generally crystallizes in cubes, gives cubo-octahedrons if the solution contains urea. Ammonium chloride and bromide, which separate in trapezohedrons from an aqueous solution, crystallize in cubes if the solution contains urea or chromium chloride; while if it contains ferric chloride, the ammonium chloride separates in cubes and the bromide in trapezohedrons; the reverse being the case when the solution contains a lead halide. Ammonium iodide crystallizes in cubes from aqueous solutions and from those containing urea, while the crystals are octahedrons if the solution contains chromium or ferric chloride or a lead halide. As to the size of crystals, the author concludes that every crystal has a maximum limit, beyond which there is no further growth. This

maximum is variable somewhat with the conditions, the volume of the solution affecting the result, up to a certain point. In proof of this he exposed crystals of alum and of magnesium sulphate, after they had reached this maximum size, to strongly supersaturated solutions for several days, without any result. This maximum size of a crystal, however, depends upon the presence of foreign substances in the solution, a crystal of salt being larger when obtained from a solution containing cupric chloride. —*Zeitschr. physikal. Chem.*, ix, 267, April, 1892. G. F. B.

2. *On the Resolution of Lactic Acid into Optically active Constituents.*—Although the asymmetric carbon theory of Van't Hoff was suggested to him by the isomerism of lactic and sarcolactic acids, no experimental proof has until now been given that inactive lactic acid is actually composed of two optically active lactic acids. This proof is furnished by PURDIE and WALKER, who have effected the resolution of lactic acid by fractional crystallization of the strychnine salt. Commercial lactic acid was diluted and boiled with water to convert the anhydride present —about 31 per cent—into acid. In the calculated quantity of this acid 460 grams of strychnine were dissolved, and the neutral solution thus obtained was submitted to fractional crystallization. Three crops of crystals were obtained which were dissolved separately in water and treated with ammonia in slight excess. The filtered solution made up to the same concentration gave rotations in a 200^{mm} tube of $+5{\cdot}46°$, $+4{\cdot}83°$ and $-1{\cdot}33°$. The first solution was boiled with zinc oxide and fractionally crystallized. The first crop of crystals proved to be the pure zinc salt of lævo-lactic acid, and gave a specific rotation $[\alpha]_D = +5{\cdot}63$. The rotation of the acid is opposite in direction to that of its salts. The mother liquors were converted into zinc salts, and by successive crystallization pure zinc dextrolactate was obtained having a specific rotation $[\alpha]_D = -5{\cdot}71°$. By mixing equal weights of the solutions of these two zinc salts, the authors obtained a solution which was optically inactive and which deposited crystals of ordinary zinc lactate.—*J. Chem. Soc.*, lxi, 754, Aug. 1892.

G. F. B.

3. *On the new element Masrium.*—In examining a native fibrous alum from Egypt, RICHMOND and OFF have detected what appears to be a new element. The alum also contained from 1·02 to 3·63 per cent of cobalt. To extract the new substance, 100 kilograms of the mineral were dissolved in water, acetic acid and sodium acetate were added, and hydrogen sulphide was passed through the solution. A white precipitate was thrown down, which was filtered off, well washed, extracted with dilute hydrogen chloride, boiled with aqua regia, diluted and filtered. On cooling a little calcium sulphate separated. This was removed and the solution was evaporated to dryness, taken up with dilute hydrogen chloride and precipitated with ammonia. The washed precipitate was dissolved in sulphuric acid and crystallized from 50 per cent alcohol. A second crystallization gave a

nearly white sulphate. This was dissolved in water and precipitated by caustic soda, in excess of which the precipitate was soluble. On adding ammonia a white precipitate came down which was dissolved in hydrogen chloride. After repeating the operation, the precipitate, on dissolving it to saturation in hydrogen chloride, gave a solution acid to litmus but absolutely neutral to methyl-orange. A portion of the solution was precipitated with ammonium oxalate and the precipitate ignited. On repeating the operation, the oxalate gave of white oxide 55·70 per cent, of oxalic oxide 15·85 and of water 31·27. Hence the authors calculate an equivalent of 122 for the oxide and of 114 for the metal; which supposing it bivalent gives an atomic mass of 228. The periodic law supposes an element of atomic mass 225 in the beryllium, calcium, strontium and barium group. The new element appears to resemble beryllium in many of its properties, zinc in others and calcium in its oxalate. Caustic soda gives a white precipitate soluble in excess, while the ammonia precipitate is insoluble in excess. Hydrogen sulphide in an acid or neutral solution of the chloride gives nothing; but in an acetic solution it gives a white gelatinous precipitate soluble readily in hydrogen chloride. Potassium chromate gives a yellow precipitate soluble in excess of the chloride, insoluble in excess of the precipitant. Sodium-potassium tartrate gives a white precipitate soluble in excess. Potassium sulphate added to a strong hot solution gives a white precipitate. Heated with cobalt nitrate the oxide gives a feeble blue color. The chloride does not crystallize. The authors have given the name Masrium to the new element, from Masr the Arabic name of Egypt. The mineral they call masrite.—*J. Chem. Soc.*, lxi, 491, June, 1892. G. F. B.

4. *On the Freezing points of very dilute Solutions.*—By the method described by him in 1884, RAOULT was able to obtain the solidifying point of ordinary solutions within one or two hundredths of a degree. To-day a greater exactness being demanded Raoult has secured it by modifying his earlier method, with regard (1) to the mode of cooling the solution and (2) to the mode of stirring it. The beaker containing the solution, previously cooled to 0°, is immersed in a 40 per cent glycerin solution, containing a spiral tube of copper, connected at each end with a vessel filled with ice and salt. The salt solution from these vessels has a temperature of $-10°$; and by regulating their relative heights, the rapidity of flow and the temperature of the glycerin solution can be regulated at will. This solution is maintained about 3° below the solidifying temperature of the liquid to be examined, so that the latter requires about 20 minutes to cool 1°. The stirrer consists of a small propeller of platinum gauze attached to the bulb of the thermometer and rotating with it. Moreover, the point of surfusion is never allowed to exceed 0·5°. As a proof of the exactness of the modified method, the author states that he finds the solidifying point of water to agree with the fusing point of ice within ·002 of one degree. Applying the new method to very

dilute solutions of cane sugar containing 0·683 parts in 100 parts of water the reduction of the freezing point is 0·042 and the molecular depression is 20·9; calling the molecular mass of the sugar 342. If the solution contains 2·848 parts of sugar, the freezing point is lowered 0·168 and the molecular depression is 20·1. For 7·297 parts in 100, the lowering of the freezing point is 0·422 and the molecular depression 19·8. For a solution of 39·040 parts, the freezing point is lowered 2·474 and the molecular depression is 21·6. Plotting the lowering of the freezing point as the abscissa and the molecular depression as the ordinate, a curve is obtained coinciding substantially, except at the origin, with one given by the author in 1886 and criticised by Arrhenius, as to the portion relating to very dilute solutions; thus confirming the original statement of the author, that when the dilution exceeds certain limits, the molecular depression of cane sugar, like that of other substances, suffers an increase. This increase is so small, however, that it appears to confirm the opinion of the Swedish chemist. These results show the advantages of the new method.—*C. R.*, cxiv, 114; *Zeitschr. physikal. Chem.*, ix, 343, April, 1892. G. F. B.

5. *Chemical Lecture Experiments. Non-metallic Elements*, by G. S. Newth. 323 pp., 8vo. London, 1892 (Longmans, Green & Co.).—The chemical lecturer will find a valuable companion in this volume, for it describes for him, clearly and with sufficient detail as to manipulation, such experiments as he is likely to need to present to his audience. For the student it is also of hardly less value, since it can be used by him in connection with the lectures which he is attending as supplementary and explanatory to them. The experiments are well chosen and cover the important properties of the non-metallic elements, including also some related physical phenomena, as the liquefaction of gases. The closing chapter is devoted to lantern illustrations, and an appendix gives a series of useful tables of chemical data.

6. *Color Photography.*—M. G. Lippman states that albumenized and gelatinized plates soaked in bichromate of potash may be employed for photographing in colors. They are used like silver salt plates. The colors appear after immersion in water which develops and fixes the image. The latter disappears on drying, but reappears when the plate is soaked. The colors are very brilliant, and are produced by the interference of hygroscopic and non-hygroscopic layers with variable refractive indices.—*Comptes Rendus*, Oct. 24, 1892. J. T.

7. *Infra red spectra of the Alkali Metals.*—Mr. Benjamin W. Snow in studying this subject has employed the bolometer with a very delicate galvanometer. The needle of the latter was suspended by a quartz fiber 40^{cm} long. With a scale distance of 3^{m} a deflection of 1^{mm} corresponded to a current of $1{\cdot}5\times10^{-11}$ amperes. A silicate-flint prism was employed to avoid the overlapping of diffraction-grating spectra. An arc light was used and a hole having been bored through the center of the carbon a

wick of the compressed salt was placed in it. The bolometer consisted of two platinum resistances. These were formed from platinum wire embedded in silver and hammered flat so as to have a breadth of $0{\cdot}05^{mm}$ and a thickness of $0{\cdot}00036^{mm}$. Two of these resistances were placed side by side on a mica frame, one was blackened and exposed to the light, the other was covered. It was found that a standard candle at a distance of 1^{m} gave a throw of 150^{mm}. A large number of carbon bands were discovered extending to wave length 20620. Sodium showed maxima at 8180, 11270, 12400 and 18360. Potassium at 7670, 10820, 11580, 12250 and 14610; lithium at 8070; rubidium at 7910, 9980, 13120 and 14760; cæsium at 8380, a large one at 8820 and other lines at 9980, 13270 and 14530.

Kayser and Runge's empirical law was confirmed for the infra red of lithium and sodium, but not for the other metals examined. —*Ann. der Physik und Chemie*, No. 10, 1892. J. T.

8. *The Magnetic effect of the Sun upon the Earth.*—Sir William Thomson, in his address at the anniversary of the Royal Society, spoke of the hypothesis that terrestrial magnetic storms are due to electro-magnetic waves emanating from the sun. The primary difficulty is to imagine the sun a permanent magnet or an electro-magnet, sufficiently powerful to produce on the earth changes of magnetic force amounting in extreme cases to $\frac{1}{20}$ or $\frac{1}{30}$ of the earth's terrestrial magnetic force, and in ordinary magnetic storms to $\frac{1}{400}$. The sun must be as a magnet at least 12000 times the average intensity of the earth's magnetism to produce by direct action, simply as a magnet, any disturbances of terrestrial magnetism sensible to the magnetic instruments in our observatories. To produce the magnetic storm of June 25, 1885, the sun must have worked at something like 12×10^{33} ergs per second, which is about 364 times the total horse power ($3{\cdot}3\times10^{33}$ ergs per second) of the solar radiation. Thus during the eight hours of a not very severe magnetic storm, the sun was doing as much work in sending forth magnetic waves through space as he actually does in four months of his regular light and heat. To Sir William Thomson's mind, this result is conclusive against the supposition that terrestrial magnetic storms are due to magnetic action of the sun; or to any kind of dynamical action taking place within the sun, or in connection with hurricanes in his atmosphere. We are forced to conclude that the supposed connection between magnetic storms and sun spots is unreal, and that the seeming agreement between the periods has been a mere coincidence.—*Nature*, Dec. 1, 1892. J. T.

9. *Sound and Music;* by the Rev. J. A. Zahm, Professor of Physics in the University of Notre Dame. 452 pp. 8vo. Chicago, 1892 (A. C. McClurg and Co.)—This is an excellent book, presenting a subject which is always full of interest in such a way as to make it doubly attractive. While accurate and scientific in its statement of the laws and phenomena of Sound, it is eminently popular, in the better sense of the word, in style and method, and

the reader is thus carried through from one chapter to the next with unflagging interest. Developed from a series of lectures delivered in Washington, in 1891, the author has retained the lecture room form, which brings him at once into close contact with his larger audience and makes them feel and share his interest and enthusiasm. The book is fresh in matter throughout, and while not aiming at originality, it gives with fullness the results particularly of recent investigations in this department; as, for example, the well-known work of Kœnig on beats and beat-tones produced by the simple notes of tuning forks, also the proof of the influence of difference of phase upon the quality of a compound musical note. It is a book which every practical musician can read and study with much profit, and which may be used advantageously by students who are approaching the subject of acoustics from a more theoretical side.

II. Geology and Mineralogy.

1. *View of the Ice Age as One Glacial Epoch.*—Mr. Upham closes an important paper on the "Accumulation of Drumlins" in the American Naturalist for December, with the following paragraphs. :

"In conclusion, I deem it a duty to state that this reference of the drumlins, terminal moraines, kames, and eskers, to rapid accumulation from previously englacial drift during the departure of the ice, seems to me better accordant with the view that the Ice age comprised only one great epoch of glaciation, attended by oscillations of the ice-border, than with the alternative view which supposes the ice-sheets to have been at least once and perhaps several times almost entirely melted away, afterward being restored by recurrent glacial epochs. This belief in the unity of our glaciation I held during my work on the New Hampshire Geological Survey in the years 1874 to 1878; but in my ensuing work on the survey of Minnesota, the peat and forest beds enclosed between deposits of till in that region led me to accept the duality or plurality of glacial epochs as taught by Croll, James Geikie, N. H. Winchell, Chamberlin, Shaler, McGee, Salisbury, and at present by most American glacialists. The recent statement by Prof. G. F. Wright of the evidence for the unity of Quaternary glaciation as the more probable view,* expresses a similar opinion with that to which I have been gradually returning, during the past year or longer, through the guidance of my investigations in this field. Moraines and drumlins are effects of secular vicissitudes of climate on the border of the departing ice-sheet. The ice-sheet, I think, owed its existence to great altitude of the land at the beginning of the Glacial period, to have been attended when at its maximum extension and volume by depres-

* "Unity of the Glacial Epoch," this Journal, III, vol. xliv, pp. 351–373, Nov., 1892.

sion of the land on which it lay, and to have witnessed, during the retreat and removal of its load, a progressive re-elevation of the same area to its present height.

"For Europe, also, after reading the recent very ably written article by Prof. James Geikie,* in which he argues for five distinct epochs for glaciation, I think that there, as here, it is more reasonable to refer the whole of the glacial drift to a single glacial epoch, with moderate fluctuations in the extent of the ice-sheets and glaciers. In thus differing from this eminent glacialist and from Wahnschaffe in Germany, Penck in Austria, and DeGeer in Sweden, who are of the same opinion with Geikie, that there were long mild interglacial epochs in Europe, I come into agreement, on this question, with other distinguished European glacialists, as Lamplugh in England, Falsan in France, and Holst in Sweden, who hold that the Quaternary reign of ice was essentially a unit. But this present state of our division under the two opinions surely calls for much further observation and candid study that ultimately the truth may be confidently known, on whichever side it may be."

2. *The Pleistocene History of Northeastern Iowa*, by W. J. McGee, pp. 189–757 of the 11th Report of the Director of the U. S. Geological Survey for 1889–90.—This paper by Mr. McGee consists of a very comprehensive discussion of the topography, soils, rivers, glacial deposits, and glacial history of northeastern Iowa. The author has presented his views in former volumes of this Journal, the latest in volume xxxv (1888). The present report gives his final results in detail and with numerous illustrating plates and maps. His general conclusions as to the glacia invasions are as follows: Over about half of Northeastern Iowa 16,500 square miles in area, there are two well-defined moraine deposits, indicative of two ice-invasions; through nearly half of the rest, lœss overlies the *two* deposits, and in a small area, only *one* of the two, and occurs over the driftless area on the borders of Wisconsin, and along the borders of the Mississippi farther south. Above the lower or older moraine deposit there is generally a bed of soil abounding in sticks, stems and other remains of trees, indicating that a forest growth covered much of the region of the lower moraine before the deposition of the upper; and besides the soils, there are locally stratified beds of sand. The two lobes of ice which moved southwestward either side of the driftless area during the second invasion, are stated to have occasioned, by their junction below, a large ice-bound lake—Lake Hennepin as named by the author; and within this lake most of the lœss of Iowa was deposited. The lœss contains freshwater and land shells, as elsewhere, and makes the most fertile land of the region. But the shells are much less than their normal size, owing, it is observed, to the coldness of the waters. "The third invasion by the ice fell short of this territory."

* "On the Glacial Succession in Europe," Trans. Royal Society of Edinburgh, vol. xxxvii, pp. 127–149, with map, May, 1892.

3. *Note on the paper in the November No. of this Journal on "A New Oriskany Fauna in Columbia Co., N. Y.,"* by S. T. BARRETT. (Communicated).—The paper entitled "Notice of a New Oriskany Fauna in Columbia Co., N. Y., with List of Fossils" by Messrs. Beecher and Clarke, containing occasional references to rocks of similar horizon near Port Jervis, N. Y., seems to me to remove much of the difficulty in the classification and division, upon faunal grounds, of the rocks in this vicinity.

If one includes the *Dalmanites dentatus* layer in the Lower Helderberg group he finds himself confronted with the difficulty amounting, I think, to an impossibility of running any dividing line at all upon grounds of faunal relationship between that layer and the strata lying above it and below the Cauda Galli Grit and there is no Oriskany.

The relations of the *D. dentatus* layer seem to be more with the rocks above than those below it. Include it, and the 100 feet of shale lying below it and above the Gray Limestone, No. 5, of my paper,* with the 50 feet extending upwards above it to the base of the Cauda Galli in the Oriskany group, and we have not only easily found boundaries, but a thickness of about 150 feet containing a fauna strongly individualized and peculiar.

The Oriskany series, thus extended from Gray Limestone to Cauda Galli, presents a fauna into which many Lower Helderberg species persist along with characteristic Oriskany species, several new to paleontology and others, according to Profs. Beecher and Clarke, which originating in the Oriskany are continued up into and reach a fuller stage of development in rocks of Lower Devonian age.

Port Jervis, N. Y., Dec., 1892.

4. *Subdivisions of the Azoic or Archæan in Northern Michigan;* by M. E. WADSWORTH. (Communicated.)—The work of the Michigan Geological Survey in 1890 made it clear that the Azoic System of the Lake Superior district of Northern Michigan was composed of at least three unconformable formations. This conclusion was published by me early in 1891, in an article entitled "A Sketch of the Geology of the Marquette and Keweenawan Districts," which was appended to a pamphlet called "Lake Superior along the South Shore." New York, 1891.

These general conclusions have been confirmed by the work of the two subsequent seasons, and two other unconformable formations rendered probable, although not yet proved conclusively. A discussion of these points will subsequently be given in detail in the reports of the State Geologist. The following are the formations as made out and named from prominent localities, by the Michigan Survey, commencing with the oldest.

There are given with this, the formations as determined by the United States Geological Survey showing their supposed equivalency.

* This Journal, vol. xiii, p. 385, 1877.

AZOIC OR ARCHÆAN SYSTEM.

Michigan Geological Survey.	U. S. Geological Survey.
Cascade Formation.	Fundamental Complex.
Republic Formation.	Lower Marquette Series.
Mesnard Formation.	
Holyoke Formation.	Upper Marquette Series.
Negaunee Formation.	

Office of the State Geological Survey, Michigan Mining School, Houghton, Michigan, October 20th, 1892.

5. *Geological and Natural History Survey of Minnesota*, Annual Report for 1890, N. H. WINCHELL, State Geologist. 255 pp. 8vo. Minneapolis, 1892.—This report consists of a translation of a memoir by Boricky on the Micro-chemical examination of minerals and rocks (80 pages), and of a paper by J. H. Kloos on Geognostic and Geographical observations in Minnesota; also a chemical report by J. A. Dodge; a report on the woods of Minnesota by H. B. Ayres; on the petrography of the Akeley Lake region by W. S. Bayley; and on the Lamellibranchs of the Lower Silurian by E. O. Ulrich.

6. *Final Report of the Pennsylvania Geological Survey*, by the State Geologist, Prof. LESLEY, vol. ii, pp. 721–1628, 8vo. Harrisburg, 1892.—The second volume of this very convenient Summary Description of the Geology of Pennsylvania, treats of the Upper Silurian and Devonian formations, and is illustrated by maps, sections, and many figures of fossils.

7. *Arkansas Geological Survey.* Annual Report for 1891, Vol. I, 144 pp. 8vo. Little Rock, 1892.—This small volume by Prof. Branner treats of the mineral waters of Arkansas.

8. *Geological Map of Baltimore and its Vicinity.* Published by the Johns Hopkins University.—This map is based mainly on materials belonging to the U. S. Geological Survey and especially for the outlines of the sedimentary formations, on the work of N. H. Darton. It has been prepared by Prof. George H. Williams, who has shown excellent judgment in the selection of colors and in the various details. It is a beautiful and highly instructive map.

9. *Devonian Fishes of Canada.*—A. S. WOODWARD describes, in the Geological Magazine for January and November, 1892, and illustrates by figures, Lower Devonian fishes from Campbellton, New Brunswick. The species pertain to the genera *Protodus*, *Diplodus*, *Gyracanthus*, *Climatius* and *Acanthodes* among Elasmobranchs; *Cephalaspis;* and the Dipnoan genus *Phlyctænaspis* of Traquair. Two of the species had been previously described by Traquair and two others by Whiteaves. The author also describes, in the November number, Upper Devonian species, from Scaumenac Bay of the genera *Diplacanthus* and *Coccosteus*, with remarks on certain plates of a *Bothriolepis* of the same locality.

10. *Nepheline Rocks in Brazil.*—A paper by ORVILLE A. DERBY, on the Nepheline Rocks of Brazil is contained in the Quarterly Journal of the Geological Society for May, 1891 (vol. xlvii), in continuation of a paper on the same subject in the same Journal for 1887 (vol. xliii).

11. *Panama Geology.*—A note by M. DOUVILLÉ (Bull. Soc. Géol. de France, April, 1891) states that he has studied specimens received by him from the beds cut by the Panama canal, and has found that to the north, near Colon, the Miocene outcrops and is very fossiliferous; that beyond, occur beds characterized by an abundance of *Orbitoides* and the presence of *Nummulites*, indicating the presence of the Oligocene. Along the southern part of the canal, to the Pacific, there occur lignitic beds of the Eocene. All the beds are horizontal or but little inclined.

12. *Geological Map of Scotland* by Sir ARCHIBALD GEIKIE (John Bartholomew & Co., Edinburgh).—This finely colored geological map, 30×26 inches in size, is an interesting study for the geologist from many points of view. One of the most instructive parts is the multitude of dikes of igneous rocks, which cut through the rocks in various directions, part following the great valleys in nearly parallel interrupted lines, and others crossing the country irrespective of topographical features. All the great formations are represented excepting the Tertiary. The map is accompanied by 23 pages of text giving a brief review of the geology of Scotland.

13. *Quaternary Carnivores found on the island of Malta.*—Until recently the known extinct Quaternary Mammals of Malta have included only Herbivores. "Nature" of November 17 announces (from the "Mediterranean Naturalist" of Malta) that Mr. J. H. Cooke, in excavating last spring the Har Dalam cavern, found, along with hundreds of bones of *Hippopotamus Pentlandi*, *Elephas mandraensis*, *Cervus barbaricus* and of many other species, discovered an entire ramus of the lower jaw of a bear, *Ursus arctos*, and teeth also of a species of wolf.

14. *Excavation by Glaciers.*—Prof. Baltzer, of Berne, has made preparations for investigating the "Erosive action of Glaciers" in the valley of the Grindelwald glacier. He states that according to his examinations the work of excavation is partly simple abrasion, and partly splintering or crushing, especially in the region where limestone is the exposed rock. He has bored 15 holes 1 to 2 meters deep in the limestone at the smoother and otherwise most favorable spots. The glacier of the Grindelwald is now commencing its new advance and therefore offers special facilities. Moreover, owing to the variations of the seasons, he hopes to obtain conclusions in the course of two or three years.—*Arch. Sci. Phys. et Nat. Geneva*, Nov. 15, 1892.

15. *Chamberlin on the Glacial period.*—Prof. Chamberlin's reply to the paper by Prof. G. F. Wright on the Unity of the

Glacial epoch is unavoidably deferred to the following number of this Journal.

16. *Mikroskopische Physiographie der petrographisch wichtigen Mineralien* von H. ROSENBUSCH. *Dritte Auflage.* 712 pp. Stuttgart, 1892. (E. Schweizerbart'sche Verlagshandlung — E. Koch.)—Nothing is more significant of the great progress in recent years in petrographical and mineralogical research than the appearance of this important work in its third edition. In thus keeping this book abreast of the times Prof. ROSENBUSCH is continually placing all petrographical students and investigators under deep obligation. The new edition contains much newly added matter, new methods of research and of determination of physical constants, the latest corrections in the optical and chemical constitution of the mineral species, with added observations upon their occurrence, alterations, etc. Besides this, many new mineral species have been added, that the progress of research has shown in the last half dozen years are to be regarded as important rock-forming constituents. A large part of these latter are the minerals described by Brögger from the eleolite-syenite of southern Norway but among them will be found such species as allanite, chondrodite, dumortierite, lasurite, lazulite, pectolite, piedmontite, prismatine, sapphirine, xenotime, etc., as examples. The addition of these species cannot fail to stimulate petrographical research. The index to literature has been removed and the author promises it undivided in a new edition of the second volume which it is to be hoped will soon appear. L. V. P.

17. *Die Gesteine de Ecuatonanische West Cordillere. Inaug. Diss.* M. BELOWSKY, Berlin, 1892. 70 pp.—This work is a continuation of that of Küch on the rocks collected by Reiss and Stübel.* After a short notice of some gneisses, mica schists and diabases, the main body of the work is devoted to a description of series of andesites and dacites. These are described as to their structure and mineral composition with great minuteness but no analyses are given nor are their chemical relationships discussed. It is to be hoped that these points may be taken up in a later work of the series. L. V. P.

18. *Chemical Contributions to the Geology of Canada, from the laboratory of the Survey*, by G. CHRISTIAN HOFFMANN, 1892. —This report contains a number of valuable contributions to the Mineralogy of Canada. Among others is to be noted the occurrence of a massive cobaltiferous arsenopyrite, or *danaite*, in the township of Graham, Algoma, Ontario. An analysis by R. A. A. Johnston, after deducting 4·77 p. c. quartz, gave:

	As	S	Fe	Co	Ni	Sb	Au
G.= 5·988	42·22	18·84	33·32	4·09	0·93	0·60	*tr.* = 100

The rare mineral *gersdorffite*, not before noted in Canada, has been found in the township of Denison, Algoma, where it occurs

* W. Reiss und A. Stübel: Reisen in Süd Amerika; Geolgische Studien in der Republik Columbia, I Petrographie 1 Die vulkanischen Gesteine bearbeitet von R. Küch, Berlin, 1892.

with niccolite, pyrrhotite, chalcopyrite, etc. It occurs massive and lamellar with occasional octahedral crystals. An analysis by Johnston gave, after deducting 13·55 p. c. SiO_2 the following results:

As	S	Ni	Fe	Co	Cu
46·96	16·71	26·32	7·90	2·01	0·10 = 100

The results of an examination of some thirty nickel and cobalt ores is given. Most of these are identified as pyrrhotite and show amounts of nickel varying from a trace up to 4 per cent. Two nickel minerals from the Vermilion mine, Denison, Algoma, gave respectively 9·40 and 40·80 per cent of nickel. An analysis is given of the harmotome from the Beaver mine, O'Connor, Thunder Bay. A hygroscopic opal from Savona Mt., B. C., containing 7 p. c. H_2O, lost 3·25 in a dry atmosphere at ordinary temperature retaining the rest; in a moist atmosphere it regained this and 3·50 p. c. in addition.

19. *On the presence of Magnetite in certain Minerals and Rocks.*—Prof. Liversidge has undertaken to solve the question as to the cause of the magnetic character of certain minerals, such as hematite, franklinite and others. Upwards of fifty specimens were examined and by the same method in each case, viz: the mass was pulverized finely in a porcelain or agate mortar and then the magnetic portion separated by a rather feeble electro-magnet. The results show that while the magnetic properties of pyrrhotite unquestionably belonged to the mass, as always assumed, those of chromite, franklinite, spinel, garnet and some hematite, limonite, and other minerals and rocks examined, were due to scattered particles of magnetite. For example, a dark compact hematite from Elba yielded 15 per cent of magnetite; a specimen of franklinite from New Jersey yielded 32·23 per cent of magnetic particles; a chromite from New Caledonia yielded 0·7 p. c.; a number of serpentines gave from a trace up to 14 p. c.

The author also shows that iron sesquioxide obtained by precipitation from the acid carbonate of iron is magnetic; also that magnetic iron sesquioxide can be obtained by heating the magnetic oxide; further, that ordinary iron rust formed under atmospheric conditions by the oxidation of metallic iron is usually magnetic and polar.—*Trans. Austral. Assoc. Adv. Science*, 1891.

20. *Manual of Qualitative Blowpipe Analysis and Determinative Mineralogy*, by F. M. Endlich. 456 pp. 8vo. New York, 1892 (The Scientific Publishing Company).—Dr. Endlich has given us in this volume a very thorough discussion of the subject of Qualitative Blowpipe Analysis, developing the many methods and reactions employed with a fullness which may fairly be said to be exhaustive; a beginner might indeed be pardoned for feeling a little overwhelmed by the amount of matter placed before him. The author's wide experience in the use of the blowpipe has enabled him to discriminate between the many reactions which have been proposed, to develop a number of new ones, and

throughout to describe the necessary manipulation with the minuteness and care needed in practical work. About half the volume is given to the discussion of the different methods of examination and the reactions of different substances and their compounds; the remainder is devoted to determinative mineralogical tables based first upon physical characters and then upon blowpipe and chemical tests. The use of these tables is facilitated by a number of examples fully explained in advance, but the student using them will regret the absence of an index to the names of species.

III. Miscellaneous Scientific Intelligence.

1. *Geminid Meteors of Dec. 11, 1892.*—Dr. Elkin saw on the evening of Dec. 11th, a goodly number of shooting stars. Between $10^h\ 50^m$ and $11^h\ 10^m$ and again between $11^h\ 30^m$ and 12^h (in all 50 minutes) he saw about 25 flights, that had a radiant close to *iota* Geminorum. This radiant was determined by five flights. They were very swift and of all degrees of brilliancy, though most of them were equal to stars of the third and fourth magnitude. Three were as bright as Jupiter. At 2^h A. M. of the 12th in two minutes he saw none.

Dr. Chase counted 39 between $10^h\ 40^m$ and 12^h. Several exceeded first magnitude stars in brightness. The flights were rapid and often long, 20° or upwards. The radiant was near *iota* Geminorum, perhaps 2° beyond iota from the middle point of line joining Castor and Pollux. Three shooting stars seen by him about eight o'clock probably belonged to the same group, but at that time failed to attract much attention. H. A. N.

2. *La Planète Mars et ses Conditions d'Habitabilité par* Camille Flammarion. 608 pp. Paris, 1892 (Gauthier-Villars et Fils).—Flammarion's volume deserves no less praise than to say that it should stand beside the work of Lockyer on the sun and that of Naysmith and Carpenter on the moon. Greater praise no author should expect.

The author has happily chosen the historical in preference to the topical or technical method of presentation. This was indeed almost inevitable since one topic, the physical geography of Mars, so dwarfs all others; but it adds greatly to the interest and profit of the reading to be shown how we know, as well as what we know. The time of publication is opportune. Ten years ago the material for the most interesting chapters had not been created and ten years hence it is not likely to be greatly enlarged.

The history of the planet is divided into three periods. The first, beginning with a drawing by Fontana in 1636, extends to 1830 and established the main surface markings, the polar caps and their changes with the seasons and also the existence of a cloud bearing atmosphere. The second period, inaugurated by Beer, Maedler and Sir John Herschel, extends to 1877. The third, to the present

summer, is chiefly made up of the astonishing work of Schiaparelli, and those inspired by him. It has given us elaborate topographical maps distinguished by the unique features known as channels (*canaux*) and has satisfactorily proved that many of these sometimes appear doubled and otherwise strangely modified to the point of entirely disappearing. It has also sown the seeds of theories which are now springing up in rich profusion and confusion.

To history the author devotes 490 pages and 268 illustrations.

The remaining 100 pages are devoted to the conclusions which the author regards as proved beyond controversy. The last two chapters, treating of the channels, rivers, continental areas, water circulation and conditions of life on the planet, will naturally excite the most interest and criticism. W. B.

3. *Investigation of the Coral Reefs of the West Indies.*—A letter from Prof. ALEXANDER AGASSIZ of December 3, states that he will soon start on an exploring trip of three months among some of the islands of the West Indies—the use of a yacht for the purpose having been generously tendered him by the Hon. John M. Forbes of Milton, Mass. He will study the reefs of the Bahamas and vicinity and those also of the north shore of Cuba from Cape Mayzi to Havana, and probably visit also for the same purpose the Bermudas. Mr. Emerton and a son of Prof. Mayer of the Stevens Institute will accompany him as draughtsmen. Mr. Mayer has been studying at Cambridge for the last two years and is especially interested in the Jelly Fishes.

4. *Gelatine slides for lantern projection.*—Prof. W. J. WAGGENER states that he has been very successful in making diagrams and pictures for projection by the magic and the solar lantern by printing the same, with the ordinary printing press and engraved blocks, on sheets of transparent gelatine. By this means excellent lantern slides from diagrams and engravings of nearly if not quite all kinds can be made and multiplied as rapidly and almost as cheaply as paper prints. The extreme of cheapness in the production of the pictures can be reached by assembling many engraved blocks together and printing all at once on large sheets of gelatine or celluloid, which can be afterward cut into pieces of suitable size.

5. *Transactions of the Texas Academy of Science.* Vol. I, No. 1, 44 pp. 8vo, Nov., 1892, Austin, Texas.—This first number of the Transactions of the Texas Academy contains short papers by A. Macfarlane, E. T. Dumble, W. F. Cummins, W. H. von Steernwitz, G. Everhart and G. W. Curtis.

6. *Die Klassiker der exakten Wissenschaften, herausgegeben* von W. OSTWALD (W. Engelmann, Leipzig).—Attention has been called repeatedly in these pages to the issues of this valuable series. Nearly forty numbers have now been published and the service thus done to the student of Physics and Chemistry can hardly be overestimated. All of the volumes are scientific classics which the worker often wishes to consult, and yet as given

in their original places of publication they are practically inaccessible to all those who have not a large library at hand. Even to those so fortunately situated the convenience of having a small, compact, inexpensive volume in hand, which can be used with perfect freedom and without fear of injury, is very great. The series should be on the shelves of every working physicist and in every physical and chemical laboratory.

The six numbers last issued are as follows:

Nos. 31, 32, 33. Lambert's Photometrie (1760), Theil I and II, III–V, VI and VII.

No. 34. Photochemische Untersuchungen von R. Bunsen und H. E. Roscoe (1855–1859): Erste Hälfte.

No. 35. Versuch die bestimmten und einfachen Verhältnisse aufzufinden nach welchen die Bestandtheile der unorganischer Natur mit einander verbunden sind von Jacob Berzelius (1811–1812).

No. 36. Ueber ein allgemeines Princip der Mathematischen Theorie inducirter elektrischer Ströme von Franz Neumann (1847).

No. 37. Betrachtungen über die bewegende Kraft des Feuers und die zur Entwickelung dieser Kraft geeigneter Maschinen von S. Carnot (1824).

7. *Royal Society of London.*—Professor H. A. Newton of Yale University, New Haven, has recently been elected a foreign member of the Royal Society.

OBITUARY.

John Strong Newberry, Professor of Geology in Columbia University, New York City, died on the 7th of December, having nearly reached the 70th anniversary of his birthday. He was born, on the 22d of December at Windsor, Connecticut, graduated at Western Reserve College in 1846, and at the Cleveland Medical School in 1848, and began the practice of medicine at Cleveland, Ohio, in 1851. In 1855 he commenced his labors in geology, the science to which, in connection with its fellow-science, paleontology, he devoted the chief part of his remaining years. He received that year an appointment of Geologist and Botanist of the expedition sent out by the government under Lieutenant Williamson to explore the region on the Pacific between San Francisco and the Columbia River; and the 6th volume of the Government Reports on a "Practicable Route for a Railroad to the Pacific," published in 1857, contains the results of his work. In 1857 and 1858 he was engaged in exploring the Colorado River on the expedition under Lieutenant Ives. The party ascended the river in a steamer for 500 miles from its mouth and brought back grand views of the wonderful scenery of the cañon, then for the first time explored for the illustration of his excellent Geological Report, as well as for that of the Commander of the Expedition. Again in 1859 he was geologist of the government expedition under Captain Macomb, which explored the country of the San Juan and Upper Colorado, and thus had an opportunity for the geological study of part of Utah, Northern Arizona and New Mexico. His report appeared,

after much delay, in 1876, in connection with the Report of an Expedition from Santa Fé to the Junction of the Grand and Green rivers. The volume contains, besides a general report of the Geology of the regions visited, descriptions by F. B. Meek of his Cretaceous fossils, and by himself of the other fossils, including Carboniferous Brachiopods and fishes, Triassic plants from Abiquiu, New Mexico, and Sonora, Mexico, the figures of the plants occupying five of the eight plates.

During the Civil War, Dr. Newberry was a member of the Sanitary Commission for the five years following September, 1861, and had chief charge of the work of the Commission in the valley of the Mississippi.

In 1866 Dr. Newberry received the appointment of Professor of Geology at the Columbia College School of Mines. In 1869 he was made State Geologist of Ohio; and the volumes published on Geology and Paleontology contain much on the stratigraphy of the various parts of the State, by him, but more on the wonderful collections of Fossil Devonian and Carboniferous fishes which the rocks afforded him and on the numerous fossil plants.

In 1888 Dr. Newberry published, in connection with the United States Geological Survey, a quarto volume of 95 pages and 26 plates on the Fossil Fishes and Fossil Plants of the Triassic rocks of New Jersey and the Connecticut Valley; and in 1889, a similar volume of 228 pages and 53 plates on the Paleozoic Fishes of North America. A Report of like completeness on the Amboy Clays (Cretaceous) of New Jersey was nearly ready for publication two years since, when a stroke of paralysis put an end to his long and most fruitful scientific labors. Besides his larger reports above-mentioned, he published many shorter papers connected with all departments of geology.

Dr. Newberry was one of the corporate members of the U. S. National Academy of Sciences. He received from the Geological Society of London the Murchison medal in 1888. From 1867 until recently he was President of the New York Academy of Sciences. He was a man of great excellence of character. While deeply devoted to Science and an earnest worker, he was yet willing to give up several years to the superintendence of Soldiers' hospitals at the time of his country's need.

Dr. Newberry leaves a widow and six children. One of his five sons is a professor in Cornell University.

Sir Richard Owen, the eminent zoologist and comparative anatomist, died in London on December 18th. He was born in 1804 and hence his active life almost spanned the century now closing; more than fifty years have passed since he was made Professor of Anatomy and Physiology at the College of Surgeons. His many contributions to science brought him distinguished honors from the highest sources and are too well known by all interested to need to be rehearsed here.

APPENDIX.

ART. VIII.—*A New Cretaceous Bird allied to Hesperornis;* by O. C. MARSH.

THE genus *Hesperornis* and its near allies have hitherto been found only in a definite horizon, the Pteranodon beds, in the Cretaceous of Kansas, and all now known have been described and figured by the writer.* Recent researches in the Cretaceous of Montana have brought to light another form distinct from *Hesperornis*, and of smaller size, but evidently belonging to the same general group of gigantic swimming birds. A single specimen only has been found, associated with marine fossils of Fox Hills types, and certainly from a much higher horizon than that in which *Hesperornis* occurs.

The specimen secured is represented one-half natural size in the figures below, and is a most characteristic part of the skeleton. It is the lower half of the right tibia of a fully adult bird. It shows that the tibia as a whole was very long and slender, with the shaft hollow throughout. In its general features, the specimen resembles most nearly the corresponding part in *Hesperornis*. The general proportions of the two are similar. The cavity in the shaft of each is equally extensive, and is bounded by smooth, well-defined walls. The ridge for the fibula is equally developed, indicating that this bone was proportionately of the same length in both, and probably of the same form.

* Odontornithes, 4to, Washington, 1880.

The differences between the present fossil and the corresponding part in *Hesperornis* are, however, strongly marked. In the latter, the distal end of the tibia is curved inward, and the smaller inner condyle is especially prominent below. In the present specimen, the outer condyle is the lower, and the inner one is nearly on a line with the inner margin of the shaft, as shown in figures 1 and 3, below. These characters are of generic importance, and hence the present specimen may be regarded as distinct from *Hesperornis*. The new genus it represents may be called *Coniornis*, and the species may be known as *Coniornis altus*.

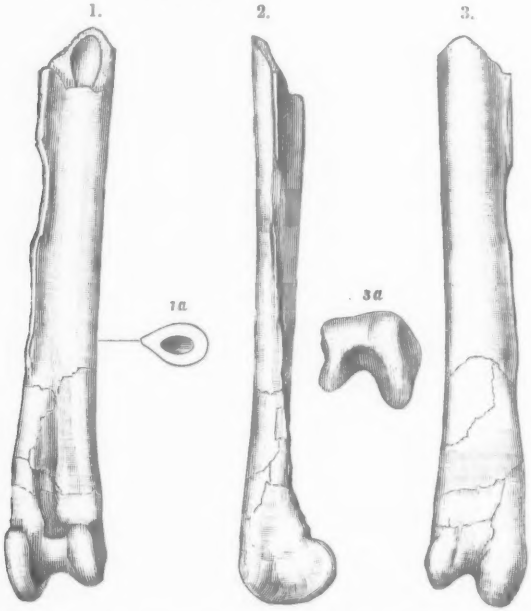


FIGURE 1.—Portion of right tibia of *Coniornis altus*, Marsh: front view.
FIGURE 1*a*.—Section of same; showing cavity.
FIGURE 2.—The same bone; seen from the right.
FIGURE 3.—The same bone; back view.
FIGURE 3*a*.—The same; seen from below.
All the figures are one-half natural size.

The present type specimen indicates a bird about two-thirds the size of *Hesperornis regalis*, Marsh, or about four feet in length, from the point of the bill to the end of the toes. It was recently found by Mr. J. B. Hatcher, near the mouth of the Judith River, in Montana.

New Haven, Conn., Dec. 12th, 1892.

Art. IX.—*The Skull and Brain of Claosaurus;* by O. C. Marsh. (With Plates IV and V.)

In previous numbers of this Journal, the writer has described and figured various remains of Cretaceous Dinosaurs belonging to the genus *Claosaurus*, and a restoration of one very perfect specimen was given in the number for October last.* Another specimen apparently of the same species has the skull in remarkable preservation, thus affording an opportunity to make out all its principal characters. This skull is well represented in the accompanying plates, and the description is given below. The brain in this genus had many points of interest, and a cast of the brain-cavity is also described briefly and figured in the present communication.

The Skull.

The skull of *Claosaurus* is long and narrow, with the facial portion especially produced. The anterior part is only moderately expanded transversely. Seen from the side (Plate IV, figure 1), the skull shows a blunt, rugose muzzle, formed above by the premaxillary and below by the predentary, both probably covered in life with a thick, corneous integument.

Behind the upper part of this muzzle is an enormous lateral cavity, which includes the narial orifice, but was evidently occupied in life mainly by a nasal gland, somewhat like that in the existing Monitor, and also seen in some Birds. This cavity is bounded externally by the nasal bone and the premaxillary. The median septum between the two narial orifices was only in part ossified, the large oval opening now present in the skull probably having been closed in life by cartilage.

The orbit is very large, and subtriangular in outline. It is formed above by the prefrontal, frontal, and postfrontal, and below mainly by the jugal. There are no supra-orbital bones. A distinct lachrymal forms a portion of the anterior border. The infra-temporal fossa is large, and is bounded above by the postfrontal and squamosal, and below by the jugal. The quadrate forms a small portion of the posterior border.

Seen from in front (Plate IV, figure 2), the skull of *Claosaurus* is subovate in outline, with the narrow portion above. The premaxillaries and the predentary bone forming the rugose muzzle are especially massive and prominent, and the powerful lower jaws seem out of proportion to the more delicate bones of the cranium.

* This Journal, vol. xxxix, p. 423, May, 1890; vol. xliii, p. 453, May, 1892; vol. xliv, p. 171, August, 1892, and p. 344, October, 1892.

Seen from above (Plate IV, figure 3, and Plate V, figure 5), the structure of the skull itself is shown to the best advantage. In front are the large premaxillaries, deeply excavated for the nasal openings. These bones are separate, and each sends back a long, slender process inside the anterior projection of the nasal, and a still longer process forming the lower border of the narial orifice, and extending to the lachrymal. The front of the premaxillaries is especially massive, and its surface rugose, indicating that it had been covered with a horny beak. The lower border is sharp, conforming to the corresponding surface of the predentary bone, which was doubtless also enclosed in a horny covering. The premaxillaries were entirely without teeth.

The nasal bones are long and slender, and especially produced in front, where they embrace the posterior median extensions of the premaxillaries. They also meet the lateral processes of the premaxillaries behind the nasal openings, and likewise touch the lachrymals. Further back, they meet the prefrontals, and closely unite with the frontals, as shown in Plate IV, figure 3.

The frontal bones are quite short, and nearly as wide as long. They are united to each other by a well-marked suture. Their upper surface is smooth, and there is a slight depression on either side, posterior to the suture with the prefrontals. Each frontal bone forms a portion of the upper border of the orbit, and behind this meets the postfrontal. Posteriorly, the frontals form the anterior border of the supra-temporal fossæ, and between these unite by suture with the coössified parietals.

The latter bones are quite small, and appear on the upper surface of the skull mainly as a narrow ridge separating the supra-temporal fossæ, and ending behind in a point, between the median processes of the squamosals. The parietals expand below, where they cover the posterior portion of the brain-cavity.

The squamosal bones are robust, and their position and connections are well shown on Plate IV, figures 1 and 3. On the median line above, they meet the narrow extension of the parietals, and exterior to this, they form the posterior borders of the supra-temporal fossæ. In front, they unite by a strong process with the posterior branch of the postfrontals. Their posterior border is joined mainly to the exoccipitals. On the outer surface of each squamosal, there is a deep pit to receive the head of the quadrate, and in front of this, a short narrow process extends down the quadrate, forming a part of the border of the infra-temporal fossa.

The quadrate bone and its main connections are shown on Plate IV, figures 1–3. It is firmly supported above by the

squamosal, but its distinct, rounded head indicates the possibility of some motion. On the outer surface in front, it joins by open suture the strong jugal bone, and below this, unites with the small, discoid quadrato-jugal. Its inner margin extends forward into a broad, thin wing for union with the pterygoid. The lower extremity is massive, and moderately expanded transversely for articulation with the lower jaw.

The jugal is one of the most characteristic parts of the skull, as may be seen from the figures on Plate IV. Its main portion is robust, much compressed, and convex externally. On its upper margin, it forms the lower border of the orbit and of the infra-temporal fossa, sending up a strong process between them, which extends inside and in front of the postorbital branch of the postfrontal. In front, it is strongly united to the maxillary, and above joins by suture with the lachrymal.

The maxillary bone in *Claosaurus* is of moderate dimensions, and seen from the outside is overshadowed by the premaxillary and jugal, as shown in Plate IV, figure 1. Its lower dentary border is thickly studded with a regular series of teeth, which slightly overlap those of the lower jaw. From above, only a small portion of the maxillary is visible, as seen in Plate V, figure 5, *m*.

The lower jaws are long and massive. The predentary bone is robust, and especially fitted for meeting the strong beak above. The dentary bones are large and powerful, with elevated coronoid processes. The angular and surangular bones are, however, quite short, and not especially strong.

The Teeth.

The teeth of *Claosaurus* are confined entirely to the maxillary and dentary bones. In each, the teeth are very numerous, and are arranged in vertical series, so that they succeed each other as the functional teeth are worn away. This is seen in Plate V, figures 1–3, which show the form of the teeth and their relations to each other in the same series. The number of teeth in each series depends upon the position, those near the middle of the jaw having the greatest number, sometimes six or more. The teeth of the upper jaw have the external face of the crown covered with enamel and ridged. In the lower jaw, this is reversed, the ridged face of the crown being on the inside. This arrangement greatly increased the cutting power of the jaws. The food was probably soft vegetation.*

*In describing the skull and teeth of *Hadrosaurus*, an allied form, Cope made many serious errors, among them the following: the predentary bone is mistaken for the dentary, the dentary is regarded as the surangular and as the splenial, while the squamosal is called the parietal. (Proc. Phil. Acad., 1883, p. 97, plates vi–vii.) Another mistake in the same paper is the statement that the name *Atlantosauridæ* was given in 1882. It was given by the writer in 1877. See this Journal, vol. xiv, p. 514.

The Brain.

The brain of *Claosaurus* was very small, its size in proportion to the skull being represented in Plate V, figure 5, which also shows the exact position of the brain in the cranium. A cast of the brain-cavity is shown in the same plate, figure 4, one-fourth natural size. The brain as a whole was considerably elongated, especially the posterior half. The olfactory lobes were well developed, and not separated by an osseous septum. The cerebral hemispheres were comparatively large, forming nearly or quite half of the whole brain. The optic lobes were narrow, but considerably elevated. The cerebellum was rather small, and also much compressed. The medulla was of good size, and nearly circular in transverse outline. The pituitary body was quite large. The interpretation of some of the more minute features of the brain is a matter of difficulty, and will be more fully discussed elsewhere.

The specimens here described were obtained by Mr. J. B. Hatcher and Mr. A. L. Sullins, in the Ceratops beds of the Laramie, in Wyoming. In the same horizon were found other herbivorous Dinosaurs, especially the gigantic *Ceratopsidæ*, and with them various small Cretaceous mammals.

New Haven, Conn., Dec. 14th, 1892.

EXPLANATION OF PLATES.

PLATE IV.

FIGURE 1.—Skull of *Claosaurus annectens*, Marsh; seen from the left.
FIGURE 2.—The same skull; front view.
FIGURE 3.—The same skull; seen from above.
All the figures are one-tenth natural size.

PLATE V.

FIGURE 1.—Series of five lower teeth of *Claosaurus annectens*; inner view.
FIGURE 2.—The same teeth; side view.
FIGURE 3.—The same teeth; outer view.
The figures are one-half natural size.

FIGURE 4.—Brain cast of *Claosaurus annectens*; side view; one-fourth natural size.
c, cerebral hemispheres; *cb*, cerebellum; *m*, medulla; *ol*, olfactory lobe; *on*, optic nerve; *op*, optic lobe; *p*, pituitary body.

FIGURE 5.—Skull of *Claosaurus annectens*, with brain cast; top view; one-tenth natural size.
a, nasal opening; *b*, orbit; *e*, infra-temporal fossa; *d*, dentary; *e*, exoccipital; *f*, frontal; *fp*, postfrontal; *j*, jugal; *l*, lachrymal; *m*, maxillary; *n*, nasal; *pf*, prefrontal; *pm*, premaxillary; *q*, quadrate; *qj*, quadrato-jugal; *s*, squamosal.

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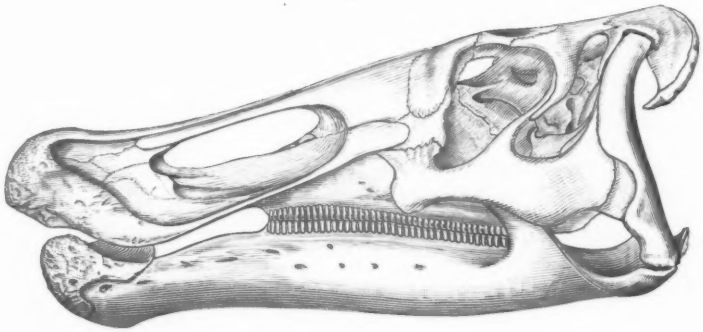

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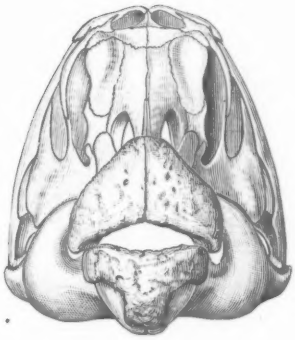

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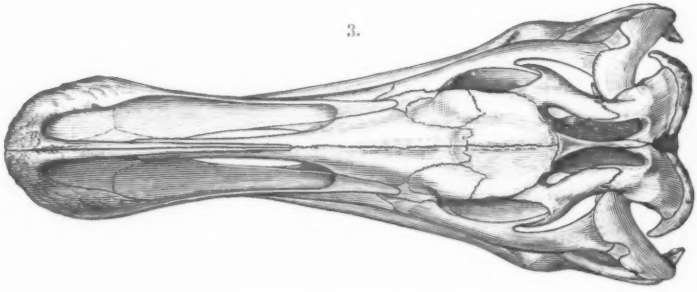
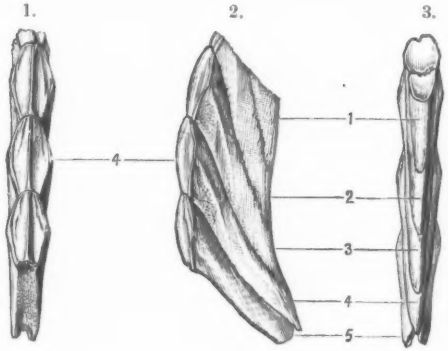


CLAOSAURUS ANNECTENS, Marsh.



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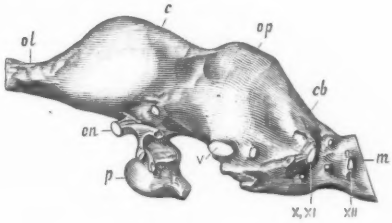

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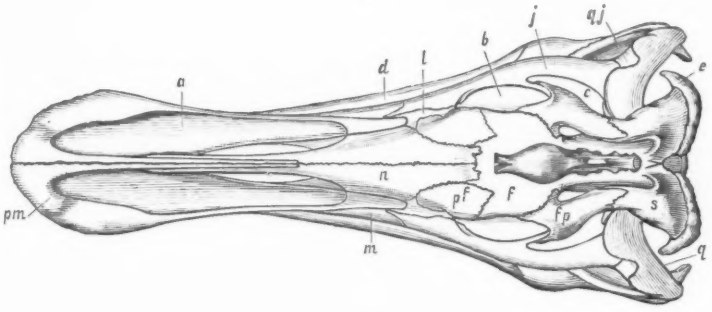

CLAOSAURUS ANNECTENS, Marsh.